

For Reference

NOT TO BE TAKEN FROM THIS ROOM

Ex LIBRIS
UNIVERSITATIS
ALBERTAENSIS



THE UNIVERSITY OF ALBERTA

ORDINATIONAL CLASSIFICATION AND STATISTICAL
ANALYSIS OF LAKESHORE VEGETATION

by



BRIAN R. PINCHBECK

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE
OF MASTER OF SCIENCE

DEPARTMENT OF PLANT SCIENCE

EDMONTON, ALBERTA

SPRING, 1972

Thesis
1950
119

THE UNIVERSITY OF ALBERTA
FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled "Ordinal Classification and Statistical Analysis of Lakeshore Vegetation" submitted by Brian R. Pinchbeck in partial fulfilment of the requirements for the degree of Master of Science.



Digitized by the Internet Archive
in 2019 with funding from
University of Alberta Libraries

<https://archive.org/details/Pinchbeck1972>

ABSTRACT

This study was conducted in a natural area which was located approximately 40 miles east of Edmonton, Alberta. The natural area was an island that was situated at the northern end of Beaverhill Lake.

The study was initiated to determine the herbage production of the area following the invasion of woody species. To test the significant changes of herbage production, the community structure of the island vegetation was determined.

The vegetation on the island was sampled during 1970 using conscious stand selection. However, it was found that the successional nature of the island vegetation rendered conscious stand selection unsuitable. In 1971, a restricted random method of plot location was employed to obtain a more representative sample of the vegetation. Three study units were delineated for sampling. These were the reconnaissance, gradient and island study units.

In this study, the ordination and cluster analysis techniques have been combined. The vegetation analysis technique resulting from this combination has been termed ordination classification.

The analysis of these study units revealed that clusters of vegetation were easily defined and the relationships among these clusters were clearly presented in orthogonal cluster ordination. It was found that the cluster distribution along the first (X) orthogonal axis was significantly correlated with elevation, soil moisture, tree and shrub density, depth of organic soil and the amount of sodium in the soil. The second (Y) orthogonal axis was significantly correlated with June soil temperature, forb weight and annual herbage weight while the

third (Z) orthogonal axis was significantly correlated with amount of available phosphorous, elevation, soil pH and soil moisture.

The X-axis defined the clusters which fell into the upland and lowland zones while the Y and Z axes separated the clusters within the upland and lowland zones, respectively. Three vegetation associations were formed from the ordinations and field data. These were:

- (a) the *Cirsium* - *Scirpus* shoreline association,
- (b) the *Calamagrostis* - *Carex* low-moor association, and
- (c) the *Populus* - *Salix* woodland association.

A fourth association, the *Poa* - *Melilotus* grassland association, was formed when the vegetation was intensively sampled.

It was found that the annual herbage production of the *Populus* - *Salix* woodland association was significantly less than the other associations. The invasion of woody species reduced the annual herbage production by 68%. The highest forb weight was produced in the *Cirsium* - *Scirpus* shoreline association while the *Calamagrostis* - *Carex* association had the highest grass and grass-like weight. Litter accounted for 62% of the available forage on the island.

ACKNOWLEDGEMENTS

I am thankful to Dr. W.H. Vanden Born, Chairman of the Department of Plant Science for making available the materials and facilities to carry out this research.

I am deeply indebted to Dr. A.W. Bailey who allowed me the freedom to investigate new avenues of vegetation analysis and for his helpful suggestions during the preparation of this manuscript. The assistance of Dr. P.D. Walton, Department of Plant Science, Dr. R.T. Hardin, Department of Animal Science, and Dr. J.W. Carmichael, Department of Bacteriology is gratefully appreciated.

I would like to thank the Department of Lands and Forests, Government of Alberta, for making available Mr. Raymond Harrison who was an enthusiastic and dedicated field assistant.

I thank Mr. Marshal Eleniak, Tofield, Alberta, for the courtesy shown to Mr. Harrison and me.

The valuable assistance rendered by the Alberta Soil and Feed Testing Laboratory is acknowledged.

The many hours of discussion with my fellow graduate students were most helpful.

To my family, Yvonne and Lara, thank-you for your patience.

TABLE OF CONTENTS

	Page
INTRODUCTION	1
DESCRIPTION OF THE AREA	3
I. Location and Size	3
II. History	3
III. Geology and Soils	5
IV. Climate	5
LITERATURE REVIEW	7
I. Marsh Vegetation	7
II. Mathematical Analysis of Vegetational Relationships	8
A. Measures of Site Resemblance	9
B. Ordination	11
C. Numerical Classification	12
D. Problems in Distance Measurements	14
METHODS	16
I. Reconnaissance Study Unit, 1970	16
II. Island and Gradient Study Units, 1971	18
A. Plot Location	18
1. Island study unit	18
2. Gradient study unit	20
B. Sub-Plot Location	20
C. Quantitative Species Values	20
D. Herbage Production Variables Collected in the Gradient and Island Study Units	21
E. Environmental and Edaphic Variables Collected in the Gradient Study Unit	21

	Page
III. Data Analysis	22
A. Ordinal Classification	22
1. Gradient and reconnaissance study units . . .	22
2. Island study unit	27
B. Statistical Analysis	27
C. Terminology and Species Statistics	29
IV. Soil Classification	30
RESULTS	31
I. Gradient Study Unit	31
A. Ordinal Classification	31
B. Statistical Analysis	44
1. Correlation and regression	44
2. One-way analysis of variance	54
II. Reconnaissance Study Unit	59
A. Ordinal Classification	59
B. Statistical Analysis	72
1. Correlation and regression	72
2. One-way analysis of variance	75
III. Island Study Unit	77
A. Plot Normalization	77
B. Ordinal Classification	81
C. Statistical Analysis	92
DISCUSSION	96
I. Species	96
A. The Degree of Dominance of a Species	96
B. Relic Species	97

	Page
II. Island Vegetation	98
A. The Lowland Zone	100
1. The shoreline association	101
2. The low-moor association	101
B. The Upland Zone	102
1. The woodland association	102
2. The grassland association	104
III. Herbage Production	107
IV. Soils of the Study Area	111
V. Ordinal Classification	114
A. Advantages	114
B. Problems	116
VI. Relevance to Range Management	117
SUMMARY AND CONCLUSIONS	118
BIBLIOGRAPHY	120
APPENDICES	123

LIST OF TABLES

	Page
1. Statistics defining the dominant species in the gradient study unit	41
2. Dissimilarity indices for the independent species	42
3. The relationship between the dissimilarity index (dependent variable) and the four statistics for the independent species in the gradient study unit	43
4. Correlation coefficients (r) matrix for all the variables in the gradient study unit as derived from 70 plot observations .	51
5. Correlation coefficients (r) matrix for all the variables in the gradient study unit as derived from 12 cluster means : . .	53
6. Correlation coefficients (r) between the cluster position on each orthogonal axis and the cluster means of the herbage production, environmental and edaphic variables in the gradient study unit	55
7. A one-way analysis of variance of each herbage production variable for the replicated clusters in the gradient study unit	56
8. A one-way analysis of variance of each environmental variable for the replicated clusters in the gradient study unit	57
9. A one-way analysis of variance of each edaphic variable for the replicated clusters in the gradient study unit	58
10. A one-way analysis of variance of each herbage production variable for the four associations in the gradient study unit	60
11. A one-way analysis of variance of each environmental variable for the four associations in the gradient study unit	61
12. A one-way analysis of variance of each edaphic variable for the four associations in the gradient study unit	62
13. Statistics defining the dominant species in the reconnaissance study unit	73
14. Correlation coefficients (r) matrix for the herbage production variables in the reconnaissance study unit	74

15.	A one-way analysis of variance of each herbage production variable for the replicated clusters in the reconnaissance study unit (kg/ha D.M.)	76
16.	A one-way analysis of variance of each herbage production variable for the three sampled associations in the reconnaissance study unit (kg/ha D.M.)	78
17.	Comparison between the cluster and sub-cluster for each of three species following the initial analysis of the island study unit raw data matrix	80
18.	The mean normalized coverage (%) of the cluster for the important species in the island study unit	82
19.	Statistics defining the dominant species in the island study unit	93
20.	A one-way analysis of variance of each herbage production variable for the replicated clusters in the island study unit	94
21.	A one-way analysis of variance of each herbage production variable for the major clusters in the island study unit	95

LIST OF FIGURES

	Page
1. Aerial photograph of the study area	4
2. Location of the reconnaissance plots on the island	17
3. Plot distribution in the island study unit	19
4. Ordinal classification diagram for the gradient and reconnaissance study units showing the related computer programs	23
5. Ordinal classification diagram for the island study unit showing the related computer programs	24
6. The three-dimensional orthogonal plot ordination of the replicated clusters in the gradient study unit	32
7. The three-dimensional orthogonal cluster ordination of the replicated clusters in the gradient study unit	37
8. The two-dimensional ordination of the independent species in the gradient study unit	45
9. Soil moisture and elevation relationships for the two gradient transects	46
10. The ecological amplitude of each independent species along transect number 8	47
11. The ecological amplitude of each independent species along transect number 10	49
12. The three-dimensional orthogonal plot ordination of the replicated clusters in the reconnaissance study unit	64
13. The three-dimensional orthogonal cluster ordination of the replicated clusters in the reconnaissance study unit	68
14. The upland-lowland ecotone	79
15. The three-dimensional orthogonal cluster ordination of the replicated clusters in the island study unit	84
16. The three-dimensional orthogonal cluster ordination of the major clusters in the island study unit	88
17. The low-moor association	103
18. A <i>Salix</i> dominated stand in the woodland association	105

19. A <i>Populus</i> dominated stand in the woodland association	106
20. The grassland association	108
21. The texture of the parent material on the study island . . .	112

LIST OF APPENDICES

	Page
1. Canopy coverage (%) of important species defining the replicated clusters in the gradient study unit	124
2. Dominant and subdominant species defining the single plot clusters in the gradient study unit	125
3. Canopy coverage (%) of important species defining the replicated clusters in the reconnaissance study unit	126
4. Dominant and subdominant species defining the single plot clusters in the reconnaissance study unit	127
5. Botanical and common names of plant species	128

INTRODUCTION

The scientific study of rangelands in Alberta has long been associated with the short and mid-grass prairie regions (Wroe, 1971). Recent works by Hilton (1970) and Wroe (1971) have been conducted in the Alberta parkland. Moss (1955) described the parkland as "a mosaic of prairie patches and aspen groves with prairie occupying the drier situations and aspen the more moist and sheltered places." It is the transition zone between the boreal forests to the north and west and the mixed prairie to the southeast. Pettapiece (1969) reported that this belt may range from stands of almost pure *Populus tremuloides*¹ forests on the northern edge to large areas of prairie with a few trees around the sloughs near the southern boundary. Bird (1961) mentioned that the northern portion was dominated by *Populus tremuloides* while the southern half by *Festuca scabrella* grasslands.

The search for agricultural land has left few areas of the parkland of Alberta unharvested. Natural undisturbed vegetation has become a rarity and the remaining stretches of virgin land should be recorded and preserved as a living record of our botanical past. The study of these natural areas attempts to provide guidelines for the proper management of parkland vegetation, preserving its character for future generations while simultaneously harvesting its resources for food production.

The objectives of this study were:

- (a) to investigate the herbage production of an undisturbed portion of the parkland belt,
- (b) to obtain natural ecological groups of vegetation, and

¹The nomenclature of the plants follows Moss (1959) and the common names have been given in Appendix 5.

(c) to statistically analyse differences among these vegetational groups for herbage production and several environmental and edaphic factors.

DESCRIPTION OF THE AREA

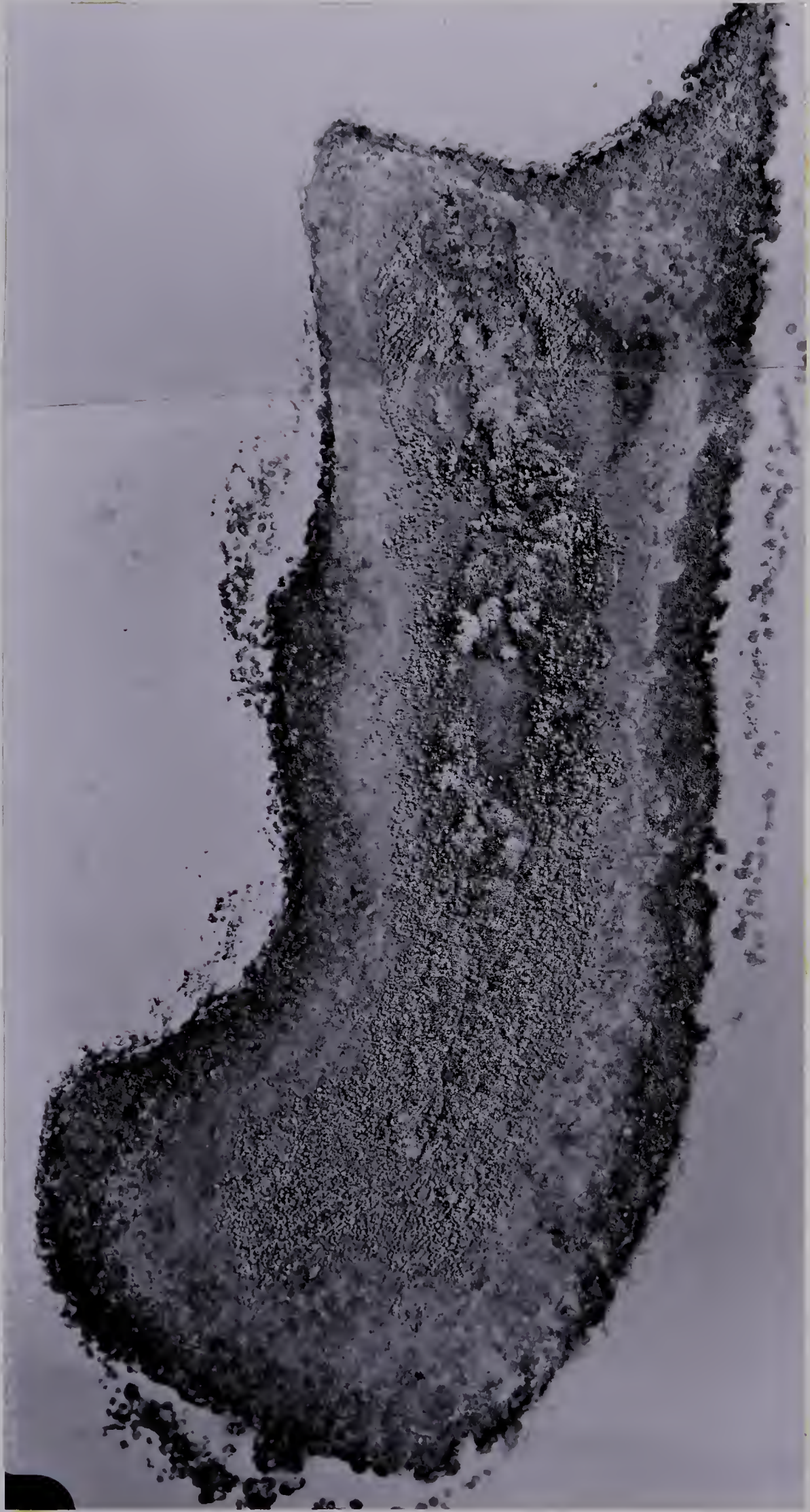
I. Location and Size

The general study area which surrounded Beaverhill Lake was approximately 40 miles east of Edmonton, Alberta. The receding water level of Beaverhill Lake has exposed approximately 10,000 hectares of land. The Government of Alberta has maintained this land for the crown and has been leasing it to the local farmers for grazing purposes. The exposed lake bed has been subjected to intensive grazing with the exception of two islands on the northern end of the lake. The smaller island, 10 hectares in size, has been the nesting colony of the Ringbill gull (*Larus delawarensis* Ord) and the California gull (*Larus californicus* Lawrence). The larger island has not been recently disturbed and was selected as the specific study area. This island, approximately 50 hectares in size, was approximately 1110 meters long and 450 meters wide. The legal description was the north half of section 24, township 52, range 18, west of the fourth meridian. An aerial photograph of the island has been presented in Figure 1.

II. History

The Water Resources Division of the Alberta Department of Agriculture reported the present level of Beaverhill Lake to be 664.2 meters above sea level. The maximum level was reported in 1915 as 667.3 meters (Anonymous, 1915). During the past 80 years there appeared to have been a cyclic pattern of low and high water levels. Early residents of the area reported that the lake was nearly dry during the early 1890's (M. Eleniak, *personal communication*). By 1915, the lake had returned to its maximum level and then again receded to a low level of approximately

Figure 1. Aerial photograph of the study area.



663.0 meters by 1949. During this latter dry period, gravel was hauled from the eastern end of the study island and hay was harvested around the island (M. Eleniak, *personal communication*).

III. Geology and Soils

Bowser et al. (1962) reported that Beaverhill Lake was located above the Bearpaw formation with the northeastern edge of the lake over the Pale Beds formation. The predominant parent material around the lake was glacial till while small pockets of fine textured lacustrine material and medium textured alluvial lacustrine material were found along the northwestern end. The predominant soil surrounding Beaverhill Lake was the Black Solodized Solonetz subgroup. The exposed lake bed was composed of coarse textured outwash material and was mapped as being in the Regosolic Order. The beach sand soils of the lake bed were considered non-arable and were not described by Bowser et al. (1962).

IV. Climate

Bowser et al. (1962) reported that the climate of the area was continental with relatively warm summers and cold winters. The May to September mean temperature was 56°F while the mean winter temperature, November to March, was 16°F. July was the warmest month with a mean temperature of 61°F while January was the coldest with a mean temperature of 6°F. The frost-free period was approximately 100 days in length.

The mean annual precipitation was 40 cm of which 70% fell as rain. June, July and August were the months of highest rainfall accounting for one-half of the total. The average snowfall in the area was about 127 cm. The November to March precipitation was almost exclusively snow.

The predominant wind direction was from the northwest with an average velocity of 16 kilometers per hour.

LITERATURE REVIEW

I. Marsh Vegetation

Moss (1955) reported that the mesic to xeric sequence on the borders of alkaline sloughs in the Alberta parkland was *Typha - Scirpus* to *Scolochloa - Carex atherodes* to *Glyceria - Carex* spp. to *Populus balsamifera*. Lewis et al. (1928) studying reed-swamps in Central Alberta, found that the common succession for non-saline large sloughs was *Typha - Scirpus* to *Scolochloa - Carex atherodes* to *Glyceria - Carex* spp. to *Calamagrostis americana - Poa palustris* to *Calamagrostis canadensis - Salix* to *Populus*. They distinguished the *Typha - Scirpus* to *Scolochloa - Carex atherodes* as reed-swamp while the remainder excluding *Populus* was termed low-moor. Lewis et al. (1928) reported that the *Scirpus - Typha* association was open and standing in several inches of water. The *Scolochloa - Carex atherodes* association was a closed community surrounding the *Scirpus - Typha* association. They also noted that when the low-moor association was continuously mowed *Juncus balticus* (ater) and *Poa pratensis* were common and that the *Calamagrostis americana* association occurred on the drier sites of the low-moor association. Moss (1953) found *Scolochloa festuacea* and *Carex atherodes* as dominants of reed-swamps of northwestern Alberta and remnants of a *Calamagrostis inexpansa - Carex atherodes* marsh.

Walker and Coupland (1968) found that *Scolochloa festuacea* showed a preference for slightly saline areas, while *Carex atherodes* favored non-saline areas. They found that mechanical disturbance at the edge of a slough resulted in the increase of *Hordeum jubatum*, *Rumex* spp., *Sonchus arvensis*, *Cirsium* spp., ¹*Taraxacum officinale*, *Polygonum aviculare* and *Artemisia biennis*. Grazing favored *Poa palustris*, *Glyceria grandis*

and *Beckmannia syzigachne*; when moist, mowing favored *Scolochloa festuacea* and *Carex atherodes*; while under drier conditions, *Poa palustris* was favored.

Bird (1961) reported that common vegetation around permanent or semi-permanent sloughs was *Carex - Scolochloa*, *Typha* and *Scirpus* zones. Fresh water sloughs were generally surrounded by a zone of *Salix* spp. with *Populus tremuloides* surrounding the *Salix* spp.

Dix and Smeins (1967) found in North Dakota that *Scirpus* spp. and *Typha* spp. were the dominant emergent marsh species while *Scolochloa festuacea* and *Carex atherodes* were commonly dominant where standing water was present for long periods. The authors found that *Calamagrostis inexpansa* and *Carex lasiocarpa* (*lanuginosa*) were associated in depressions which were inundated with water for short periods. They defined marsh as stands of *Phragmites communis*, *Typha latifolia*, and *Scirpus* spp. while meadows were dominated by *Scolochloa festuacea*, *Carex atherodes* and *Phalaris arundinacea*.

II. Mathematical Analysis of Vegetational Relationships

The structure of vegetation has been largely determined by the differential response of species to a set of environmental factors (Beals, 1960; Ayyad and Dix, 1964). The greater the similarity in the response of two species to the environmental factors of any site, the greater the chance the two species will have of being present at that site. Therefore the resemblance among sites can be determined by their species composition (Swan et al., 1969). The degree of resemblance among sites may be measured using various coefficients (Sokal and Sneath, 1963). The coefficients used in plant ecology have been the coefficients

of association and of distance.

A. Measures of Site Resemblance

The most commonly used coefficient has been that of association (Cole, 1949; 1957; Bray and Curtis, 1957; Williams and Lambert, 1959; 1961; Beals, 1960). Bray and Curtis (1957) and Beals (1960) used the Index of Similarity (S) to derive a measure of the association between vegetational sites. The Index of Similarity formula used by Bray and Curtis (1957) and Beals (1960) was $S = 2W/(A+B)$, where A was the sum of the quantitative species values (canopy coverage, frequency, density, etc.) for one site, B was the equivalent of the other site, and W was the sum of the lesser values of those species which were present in both sites. These authors transformed the coefficient of association into a coefficient of distance which they called the Index of Dissimilarity (D) by subtracting the Index of Similarity from the maximum Index of Similarity ($D = S_{\max} - S$) found in the study.

Orloci (1966) presented an alternative association coefficient which he termed the weighted similarity coefficient. This was the coefficient of principal components "factor" analysis.

The coefficient of distance has been most extensively used in numerical taxonomy (Sokal and Sneath, 1963). One coefficient, the Euclidean distance, has recently been used in plant ecology (Austin and Orloci, 1966; Orloci, 1966; Swan et al., 1969). The coefficients of distance have been based upon a geometric model (Euclidean space) which has been defined by a set of orthogonal axes (Sokal and Sneath, 1963). In plant ecology, individual sites were located according to their species composition in a Euclidean space of dimension (number of orthogonal axes) equal to the number of species present (Swan et al., 1969).

The spatial position of individual sites relative to one another can be obtained by an estimate of the intersite distance (Orloci, 1966). Orloci (1966) suggested that the intersite distance was obtained using the Pythagorean theorem. If A and B were two sites with axes values $(X_{1A}, X_{2A}, \dots, X_{NA})$ and $(X_{1B}, X_{2B}, \dots, X_{NB})$, respectively for N orthogonal axes, then their intersite distance (D_{AB}) was computed as:

$$D_{AB} = \left[\sum_{i=1}^N (X_{iA} - X_{iB})^2 \right]^{1/2}.$$

Since each orthogonal axis was defined by quantitative values of a species, the intersite distance may be computed directly from the value defining the site position on each axis (Orloci, 1966). Sokal and Sneath (1963) reported that the intersite distance increased with the number of species used and suggested the following correction:

$$D_{AB} = [(D_{AB})^2 / N]^{1/2}.$$

This has been defined by Sokal and Sneath (1963) as the average distance.

Another distance coefficient used in numerical taxonomy was the arithmetic distance (Carmichael and Sneath, 1969). The formula given was:

$$D_{AB} = \sum_{i=1}^N |X_{iA} - X_{iB}|$$

which had the same notation as the Euclidean distance. Sokal and Sneath (1963) corrected the arithmetic distance by dividing it by the number of species and called this distance the mean character difference. They suggested that this distance was simpler to use than the Euclidean distance but the mean character difference will always underestimate the true Euclidean distance between sites in Euclidean space especially when species differences were small while others were large. No record

of the usage of the arithmetic distance or the mean character difference could be found in plant ecology literature.

When all possible intersite distances were computed using any one of the aforementioned coefficients, a symmetrical matrix was produced in which the main diagonal values were zeros and the rows and columns were defined by the number of sites compared. This intersite distance matrix was the basis of the ordination technique and some numerical classification techniques.

B. Ordination

Two continuous structuring techniques used in plant ecology have been principal components "factor" analysis (Goodall, 1954; Austin and Orloci, 1966) and ordination (Bray and Curtis, 1957; Beals, 1960; Gittens, 1965a; 1965b; Austin and Orloci, 1966; Orloci, 1966; Swan et al., 1969). Ordination as defined by Swan et al. (1969) was a construction of a geometrical model which was analogous to, yet simpler to construct and comprehend than principal components "factor" analysis. Ordination has been the most popular of the two continuous structuring techniques in plant ecology.

Lambert and Dale (1964) stated that ordination was a technique whereby each site was placed in relation to all others on one or more axes. Swan et al. (1969) assumed that the distribution of many species was related to a limited number of environmental factors and that the axes defined during ordination should reflect these factors. This concept was also suggested by Bray and Curtis (1957), Beals (1960) and Ayyad and Dix (1964). The construction of the ordination axes as defined by Beals (1960), Orloci (1966) and Swan et al. (1969) were all basically similar; however, the axes construction method of Swan et al. (1969)

presented the "best stand [site]-defined axes."

Swan et al. (1969) chose the first orthogonal axis as the one which accounted for the highest proportion of the sums of squares of all intersite distances derived from the Euclidean distance. The second axis accounted for the next highest proportion of the intersite sum of squares not accounted for by the first axis. The second axis was perpendicular to the first. Other axes were constructed from the residual sums of squares. The criterion of axis selection has been fully discussed by Swan et al. (1969). They believed that their method was simpler to understand than the analogous but more sophisticated principal components "factor" analysis because it was based on axes derived from simple geometric constructions. Their method was also found to be suited to species ordination.

C. Numerical Classification

The ordination technique arranged the sites on axes with the position of each site being determined by its species composition. In classification, the sites were arranged into groups with each group having a common species composition (Lambert and Dale, 1964). Greg-Smith (1964) defined classification as the "arranging of stands [sites] into classes, the members of each of which have in common a number of characteristics setting them apart from the members of other classes." In plant ecology, two methods of finding vegetational groups from a matrix of observations have been presented; a dendogram (Williams and Lambert, 1959; 1961), and cluster analysis (Stringer, 1969). Both of these methods have been used extensively in numerical taxonomy (Sokal and Sneath, 1963; Carmichael et al., 1968; Carmichael and Sneath, 1969).

The dendogram classification as presented by Williams and

Lambert (1959, 1961) was a qualitative, monothetic, divisive and hierarchical classification system which was derived from either a normal or an inverse analysis. The major discontinuities between groups of sites were identified during normal analysis. This was accomplished by using the correlation of the presence-absence records of all possible species pairs. Inverse analysis detected discontinuities in groupings of species from the correlation of site pairs. It was found by Williams and Lambert (1959) that the site groupings could actually be mapped and were analogous to habitat discontinuities. Species groupings were found to be "merely abstractions of ecologically-related species, held together by their defining quadrat, but rarely representing the total flora of a particular site except in the case of the first hierarchical division" (Williams and Lambert, 1961). Normal analysis was a measure of differences in species richness while inverse analysis was a measure of differences in species abundance (Williams and Lambert, 1961).

Carmichael and Sneath (1969) suggested that the dendrogram could not illustrate the relationships between non-adjacent groupings. They presented a quantitative, polythetic, agglomerative and semi-hierarchical taxometric classification technique which presented the relations between clusters located in Euclidean space. Carmichael's (1970) classification was a method "where agglomeration was renewed at each level of classification, thus partitions formed at one level did not restrict those formed at another level."

The cluster analysis developed by Carmichael et al. (1968) began with a set of points in Euclidean space as defined by a set of orthogonal axes. They were interested in determining if "natural clusters" (groups of sites) existed within a Euclidean space by deter-

mining the relatedness of the sites. They concluded that sites forming a cluster must be more related than sites in differing clusters and that the relatedness of sites could be determined from the intersite distance. Sites falling within a cluster had relatively short intersite distances among themselves, and relatively long intersite distances to sites in other clusters. Carmichael and Sneath (1969) displayed their classification in a form of circles representing the clusters and lines representing the cluster relations. The authors were able to portray the cluster relations inherent within a Euclidean space and thus defined a classification technique which complemented ordination.

Stringer (1969) used ordination and cluster analysis in a study of grasslands in Banff, Jasper and Waterton Lakes National Parks in Alberta. He used the Bray and Curtis (1957) model for ordination and the George and Carmichael (1966) cluster analysis. He found that the cluster analysis verified the discontinuity between the Waterton and the Banff-Jasper stands as indicated by three-dimensional ordination. Stringer (1969) also found that cluster analysis, although complimentary to ordination, delimited more accurately the centrally located stands.

D. Problems in Distance Measurement

Swan et al. (1969) encountered problems with Euclidean distance measurements. They found that "the calculated distance between two stands increases with the number of species for which quantitative measures are available." The intersite distance between the end sites may be less than the distance to a site having more species near the center of the gradient, thus distorting the vegetational patterns and obscuring vegetation-environment relationships. This distortion may be overcome by using the average distance. They found that species

values of zero did not increase the distance between sites even though species populations were changing and that sites which were quantitatively and floristically alike may be adjacent or separated by other sites along a vegetational gradient.

METHODS

The vegetation which was delineated for sampling has been defined in the present study as a study unit. Three study units, reconnaissance, gradient and island, were selected to sample the vegetation of the island using various methods of plot location.

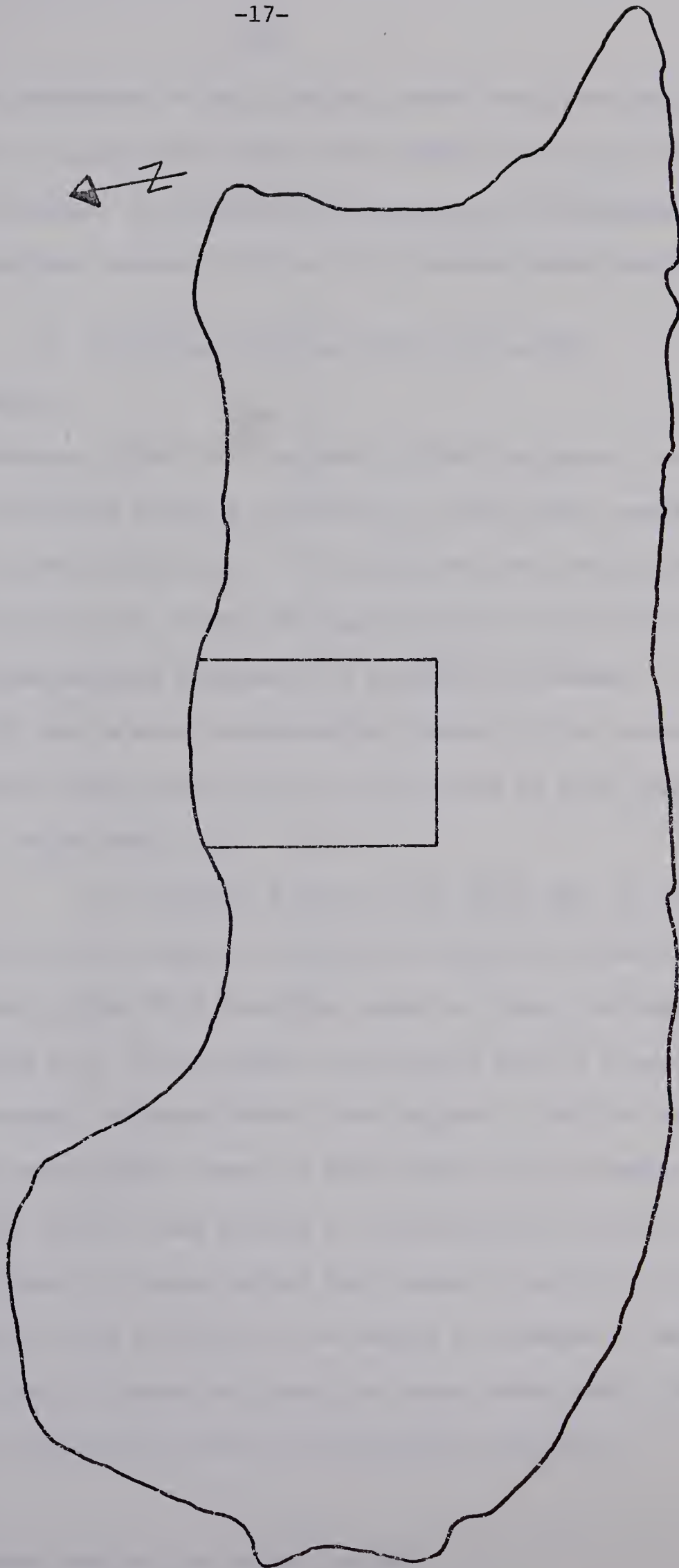
I. Reconnaissance Study Unit, 1970

Seventy line transects, five meters in length, were located within stands of five representative communities which were selected following reconnaissance (Daubenmire, 1952) of that portion of the island illustrated in Figure 2. The canopy coverage (%) class midpoint following Daubenmire (1959) was recorded for all species occupying a percentage of the line transect. The coverage classes used were:

Midpoint	Range
3	= 0 - 5%
15	= 5 - 25%
37	= 25 - 50%
63	= 50 - 75%
85	= 75 - 95%
98	= 95 - 100%

Two 20x50 cm plots, one randomly located in each 2.5 m segment, were harvested during early August 1970. The green herbage was harvested from one plot and sorted to grass and grass-like species and to forbs. Total herbage was harvested from the other as a measure of the standing crop. The collected herbage was air-dried in the laboratory and the weights of grass and grass-likes, forbs and standing crop were recorded for each appropriate plot. The annual herbage weight was determined from the sum of the grass and grass-like weight and the forb weight. One year later, a 20x50 cm plot immediately adjacent to the

Figure 2. Location of the reconnaissance plots on the island.



first plot was harvested in early August, sorted and air-dried as above, and the grass and grass-like weight, forb weight and annual herbage weight were recorded. All weights were converted to kilograms per hectare and comparisons between 1970 and 1971 herbage production were made.

II. Island and Gradient Study Units, 1971

A. Plot Location

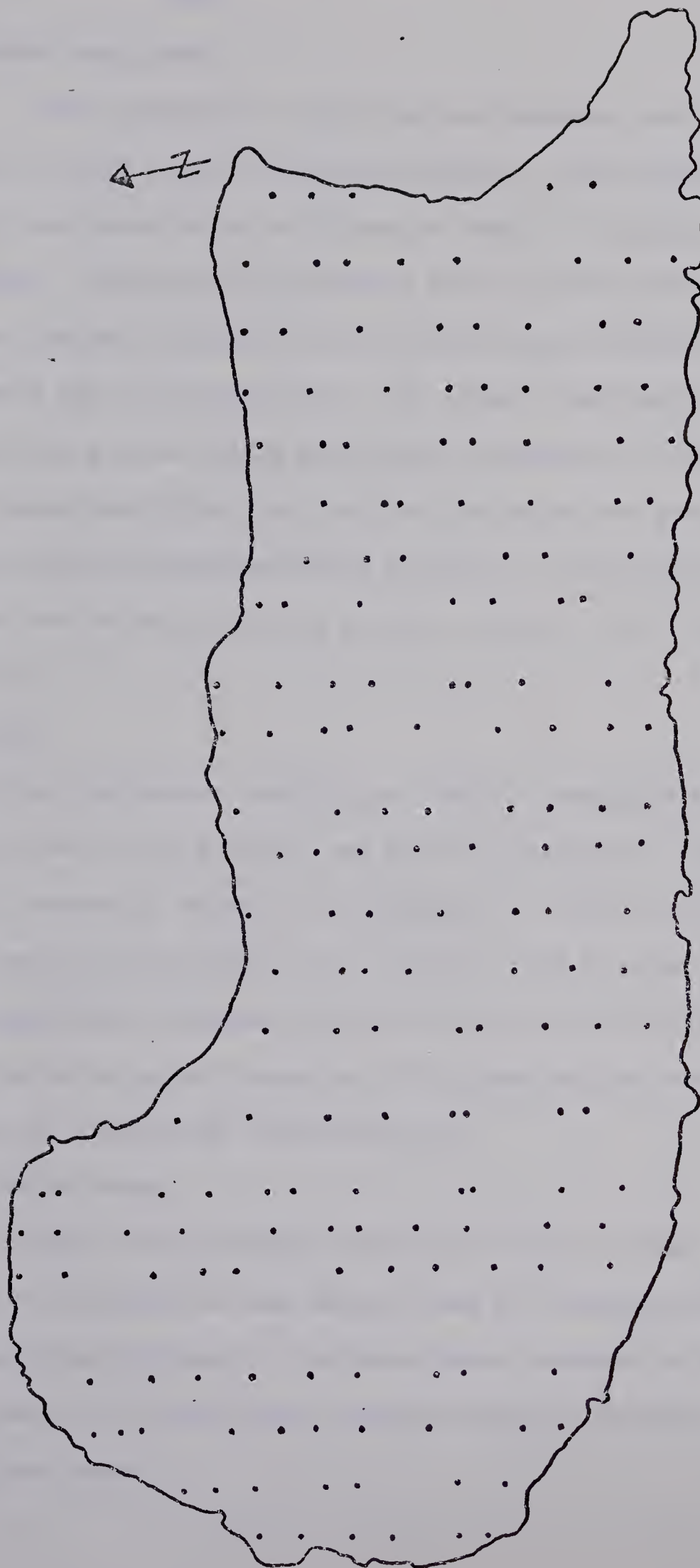
Daubenmire (1968) and Greg-Smith (1964) suggested that conscious stand selection should be practised to efficiently sample vegetation. Since the vegetation on the island had been rapidly changing during the last 40 years, stands of vegetation were difficult to delineate during the reconnaissance because relic species were common. It was decided in 1971 that a more representative sample of the vegetation would be obtained using a restricted random method of plot location.

1. Island study unit.

An arbitrary base-line was drawn east to west along the north shore of the island. Perpendicular cut-line transects were randomly located within 50 m¹ intervals along the base-line beginning from the eastern end. Each transect was divided into 50 m segments and a point was randomly selected within each segment. The plot center was located seven meters east or west of this point if the transect was located greater than or less than 25 m, respectively within the base-line segment. A distance of seven meters was chosen to avoid the cut-line effect. Each plot was a circle of two meters in diameter. The plots distributed along 23 transects formed the island study unit. The distribution of these plots has been displayed in Figure 3.

¹All measurements were to the nearest meter.

Figure 3. Plot distribution in the island study unit.



2. Gradient study unit.

Since the task of collecting environmental and edaphic data from 185 plots would have been astronomical, two transects (numbers 8 and 10) were selected for an intensive sample of the major vegetational gradient. The plots were randomly selected within 10 m segments along each transect and were located seven meters west and east of transect numbers 8 and 10, respectively. The island study plots were located first, while the gradient study plots were superimposed. Data collected for an island study plot were used for the equivalent gradient study plot; however, the plot identification differed in each study unit. Seventy-four plots were located; 36 along transect number 8 and 38 along transect number 10.

B. Sub-Plot Location

To facilitate herbaceous sampling, two 20x50 cm sub-plots were located within each plot of the gradient and island study units. The first sub-plot was located by randomly selecting one 10° point in a 180° interval whose reference was parallel to the transect with 0° being northward. The longitudinal mid-line of the sub-plot was used as the reference and the inside edge was located at 50 cm from the plot center. The other sub-plot was located 180° from the first.

C. Quantitative Species Value

Canopy coverage (%), following Daubenmire (1959), for the herbaceous species was recorded in each sub-plot and the average species cover of the two sub-plots, adjusted to the appropriate mid-point of the cover class, was used as the quantitative species value for the plot. The cover classes used were:

Midpoint	Range
1.0 =	0 - 2%
4.0 =	2 - 6%
15.0 =	6 - 24%
37.0 =	24 - 50%
63.0 =	50 - 76%
85.0 =	76 - 94%
97.0 =	94 - 100%

Species found within the plot but outside the sub-plot were recorded as 0.5% cover for the plot while species found adjacent to the plot were recorded as 0.1%. Shrub and tree canopy coverage was recorded for the plot using the midpoint of the sub-plot cover classes.

D. Herbage Production Variables Collected in the Gradient and Island Study Units

The green herbage within both sub-plots was harvested during late July and sorted in the field to a grass and grass-like sample and a forb sample. Each sample was air-dried in the laboratory and weighed to the nearest gram. Annual herbage weight for each plot was obtained by summing the grass and grass-like weight and the forb weight. These weights were then converted to kilograms per hectare.

E. Environmental and Edaphic Variables Collected in the Gradient Study Unit

Soil moisture and nutrient samples were collected on June 4, 1971 for each plot. The elevation of each plot above the lake level was also recorded. Soil moisture samples were placed in moisture tins, weighed, and oven-dried (63°C) for 48 hours. The samples were removed from the oven, re-weighed, and the moisture percentage was calculated. Soil nutrient samples were sent to the Alberta Soil and Feed Testing Laboratory to determine the pH and the amount of nitrogen, phosphorous, potassium and sodium in the upper 15 cm of soil. Soil temperatures were recorded at the center of each gradient study plot during the first week

of each of the following months: June, July and August. A temperature probe of 15 cm in depth was used and readings were made to the nearest one-half degree Centigrade. Other variables recorded were tree and shrub density and depth of organic soil.

III. Data Analysis

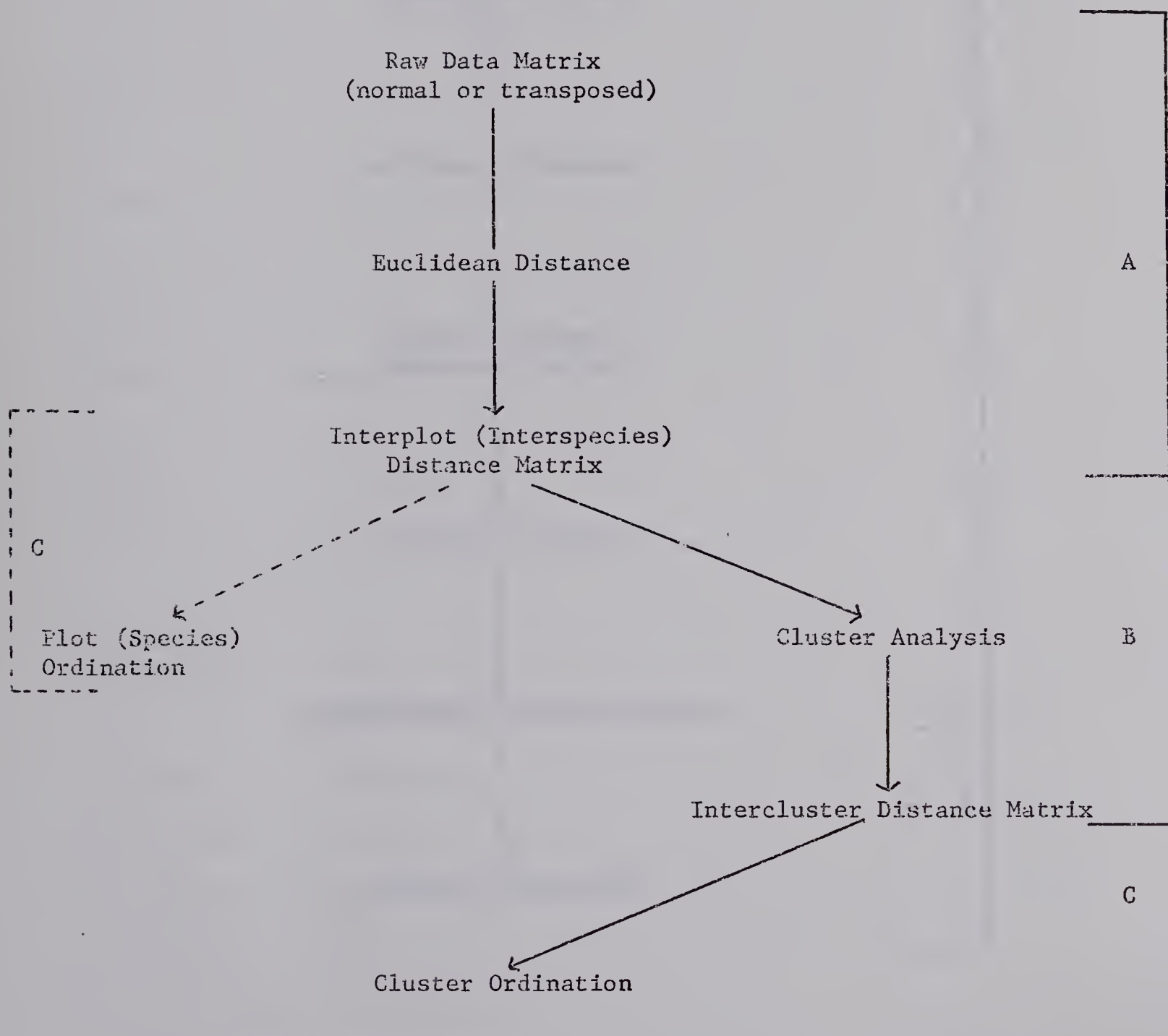
A. Ordinal Classification

The ordination technique presented by Swan et al. (1969) and the numerical classification technique by Carmichael and Sneath (1969) were chosen for the present study because they both described the relationships between plots (sites) located in Euclidean space. The distance matrix was the fundamental basis of each technique. Ordination expressed this matrix in continuous axes while numerical classification expressed the matrix in discrete clusters. In the present study the combination of these two techniques was termed ordinal classification. Ordinal classification presented the distance matrix in discrete clusters and then ordinated the intercluster distance matrix. Analysis diagrams for differing approaches to ordinal classification have been presented in Figures 4 and 5.

1. Gradient and reconnaissance study units.

The set of all plots and species for each study unit comprised a raw data matrix. This matrix was analyzed following the ordinal classification technique (Figure 4). To analyse section A of Figure 4, the Euclidean distance program EUCLID (Purchase, 1970a) was obtained and was edited for a more efficient data input. Normal and transposed raw data matrices could be analyzed with EUCLID resulting in an interplot distance matrix or an interspecies distance matrix,

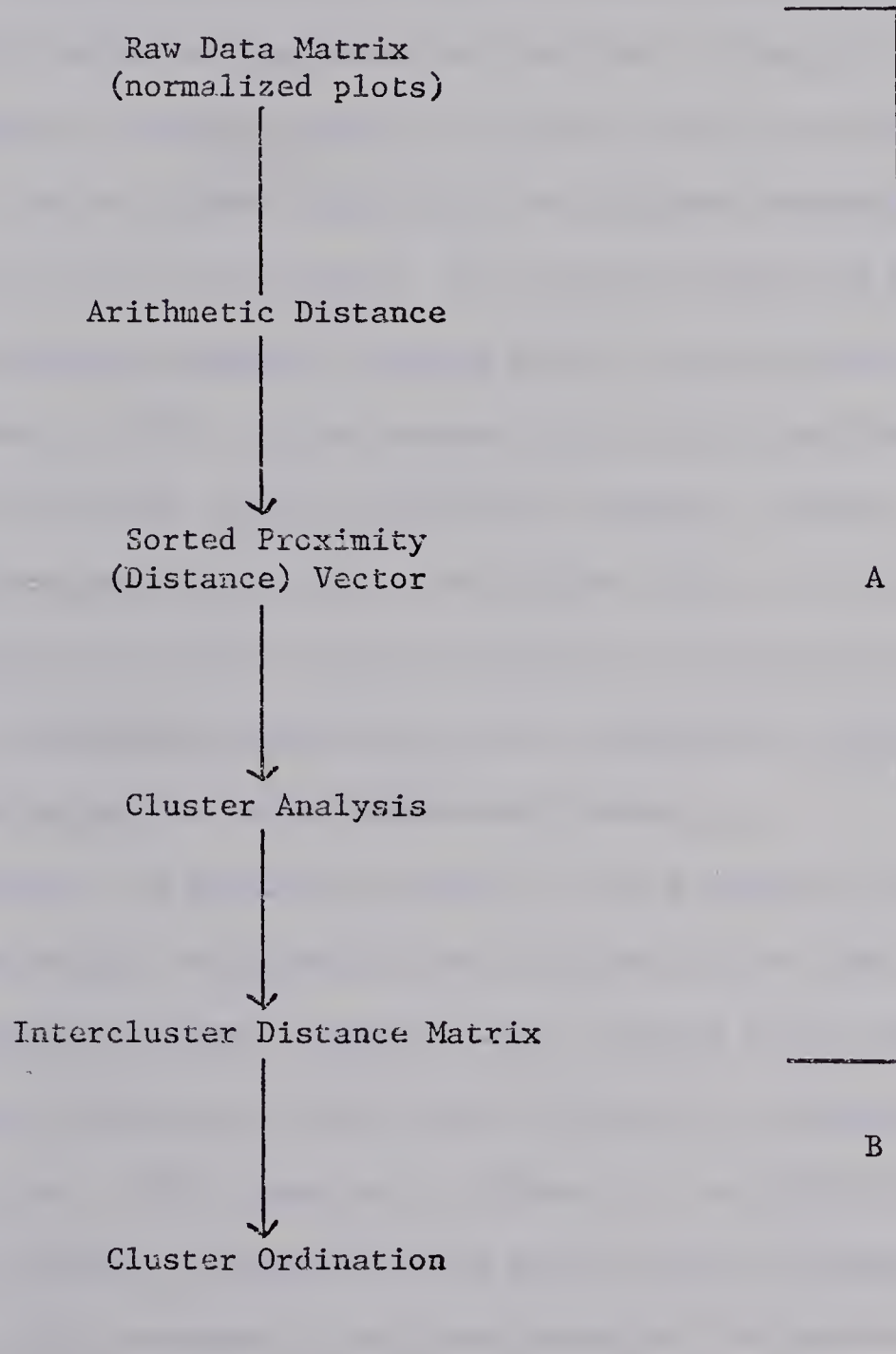
Figure 4. Ordinal classification diagram for the gradient and reconnaissance study units showing the related computer programs.



Computer programs:

- A. Purchase (1970a) EUCLID (edited)
- B. Carmichael (1970) Subroutine CLUSTER from TAXMAP (edited)
- C. Purchase (1970b) SDWORD (edited)

Figure 5. Ordinal classification diagram for the island study unit showing the related computer programs.



Computer programs:

- A. Carmichael (1970) TAXMAP (Edited)
- B. Purchase (1970b) SDWORD (Edited)

respectively. The CLUSTR subroutine from Carmichael's TAXMAP (1970) was edited to use either distance matrix. This program classified the distance matrix into discrete clusters with an intercluster distance matrix being produced during the analysis (Section B, Figure 4). The intercluster distance (cluster center to cluster center) was determined from the sum of the two cluster radii plus the distance between the nearest neighbors of the two clusters. The cluster radius was defined as one-half the maximum interplot distance which occurred within the cluster (Carmichael, 1970). In the present study, all intercluster distances were used during cluster ordination; however, only the replicated clusters were placed in the ordination field. If separation of the replicated clusters was not achieved, the position of the cluster on each axis and the cluster radii were rescaled to a percentage of the largest axis position of a replicated cluster.

To display the relative proximity of each cluster in Euclidean space, three-dimensional orthogonal cluster ordination was used. The axes of the orthogonal cluster ordination were defined by the SDWORD ordination program (Purchase, 1970b) which followed the technique discussed by Swan et al. (1969) (Section C, Figure 4). As three-dimensional ordination was difficult to display on one page, three two-dimensional ordinations have been presented. The two-dimensional ordination A presented the Euclidean space defined by the X and Y axes while B presented the X and Z axes and C the Y and Z axes. The three-dimensional Euclidean space was achieved by observing the three two-dimensional

ordinations together as one three-dimensional ordination. The position of the cluster in the ordination field was determined by the cluster center with the cluster sphere being defined by the cluster radius.

Orthogonal plot ordination axes were also defined by the SDWORD program using the interplot distance matrix (Section C, Figure 4). To define each cluster all plots within a cluster were located in the ordination field and a line was drawn around the points delineating the area occupied by each cluster. The display of the three-dimensional plot ordination was accomplished by the same method as the three-dimensional cluster ordination. The plot ordination was compared to the cluster ordination to check the accuracy of the cluster analysis.

The clusters of the reconnaissance study unit have been arranged from the most mesic to the most xeric in the output of the raw data matrix (Appendix 1) and in the one-way analysis of variance tables. The clusters of the gradient study unit have been arranged in order of increasing elevation. The plots which have been presented first in each cluster were at the center of the cluster sphere while the latter plots formed the peripheral or satellite plots (Appendix 1). The clusters were most homogeneous near the center, becoming more heterogeneous as plots were added to the cluster. Because they were not replicated, those clusters which were formed from single plots (isolated clusters) have not been included in any analysis or discussion.

The formation of vegetation associations in the gradient and reconnaissance study units was accomplished by subjectively analyzing the plot and cluster ordinations and defining with the aid of field notes, subsets of clusters which formed larger groups. The resulting associations approximately followed Lewis et al. (1928) and provided a concise

description of the major vegetational gradient.

2. Island study unit.

The plots of the raw data matrix of the island study unit were normalized so that the species with the highest canopy coverage in each plot was assigned a value of 100%. The cover values of the remaining species present in the plot were adjusted proportionately. This was done to remove the observer error which had resulted during the collection of canopy coverage data. The normalized raw data matrix was analyzed following the ordination classification technique presented in Figure 5. The taxometric mapping program TAXMAP (Carmichael, 1970) was used to define the clusters of vegetation (Section A, Figure 5). This program computed the arithmetic distance between pairs of plots and rank-ordered all the distances into a proximity vector which was used as the basic matrix during cluster analysis. This cluster analysis procedure presented the "best" set of clusters from the raw data matrix (Carmichael, 1970). The intercluster distance matrix was defined by TAXMAP following the same procedure as described in the gradient and reconnaissance study units as was the three-dimensional orthogonal cluster ordination (Section B, Figure 5). Orthogonal plot ordination was not determined for this study unit as an interplot distance matrix was not available. The arranging of the clusters in the one-way analysis of variance tables was approximately from the mesic to xeric while the isolated clusters were not included in any analysis or discussion.

B. Statistical Analysis

Other matrices were formed from the plots and herbage production, environmental and edaphic variables collected in the gradient study unit and the plots and herbage production variables of the

reconnaissance and island study units. One-way analysis of variance was performed upon each variable in the matrices to determine if significant differences ($P < 0.05$) existed among clusters. Each cluster was used as a vegetational "treatment" and the plots within a cluster were the replications within a treatment. Duncan's New Multiple Range Test was applied to the cluster means to determine which were significantly different ($P < 0.05$). Non-normal (skewed) distribution, present in some variables, resulted in a highly significant homogeneity of variance (Chi-square) test when the analysis of variance was performed on the raw data. Scheffé (1959) reported that the analysis of variance on a one-way classification could measure the F-test using treatments with unequal variances. He reported that if a variance was largest for the treatment with the greater replication, then the F-test was conservative (observed $P = 0.04$, expected $P = 0.05$). If, however, the largest variance was associated with the lesser replicated treatment then the F-test was liberal (observed $P = 0.09$, expected $P = 0.05$). Steel and Torrie (1960) discussed this same point and concluded that in biological data loss of sensitivity was unimportant. Lindquist (1971) reported that the F-test was very elastic and was able to tolerate large treatment variances without a loss of sensitivity.

Steel and Torrie (1960) suggested the use of the $\log(X+1)$ transformation of the variables to equalize the variances prior to analysis. They also suggested the use of Bartlett's test for the homogeneity of variances. It was found that the logarithmic transformation of the 1970 forb weight from the reconnaissance study unit reduced the Chi-square value in Bartlett's test from 136.2 (raw data) to 29.5 (transformed data) for 46 degrees of freedom. The Chi-square value for

the transformed variable was not significant indicating that the variances were homogeneous.

Li (1964) reported that the arithmetic mean from the logarithmic transformation was the same as using the geometric mean of the original data. He also reported that the geometric mean of a skewed distribution was closer to the median than the arithmetic mean which was affected by data in the tail of the distribution. Steel and Torrie (1960) reported that the arithmetic mean may not be the most informative central value if the distribution was skewed. The means in the present study have been presented as geometric rather than arithmetic as the cluster mean has been converted to the original scale.

Correlations between the variables in each study unit were determined using Grobbs (1970). In the gradient study unit, a multiple regression (Grobbs, 1970) was determined for the dependent variable (annual herbage weight) using coverage, environmental and edaphic factors as independent variables. A multiple regression was performed on each orthogonal axis of the cluster ordination from the gradient study unit to determine which variables were influencing the cluster distribution along each axis.

C. Terminology and Species Statistics

A species found within a study unit exhibited a frequency (Daubenmire, 1968), a presence cover (sum of the cover divided by the number of plots in which the species was present), a mean cover (sum of the cover divided by the number of plots sampled) and a prominence index (mean cover multiplied by the square root of the frequency (La Roi, 1964)). Dominant species were defined as those with the highest mean canopy coverage for the cluster and the sub-dominant species had a mean

canopy coverage which was at least 60% of the dominant. The dominant and sub-dominant species defined the cluster name with sub-dominance displayed by a dash (-) and co-dominance expressed by a slash (/). Species with a mean canopy coverage of 10% or more in the cluster were defined as prominents to distinguish them from those species which were present with a low mean canopy coverage (subordinates).

Species in the raw data matrix were arranged by the computer in decreasing order of mean cover for each study unit and an arbitrary point, approximately 1% of the maximum mean cover, was used to delimit species which were "important" from those which were "unimportant". Inverse ordination classification of the gradient study unit provided species which acted as single species clusters. These have been termed as independent species. The summation of the columns of the interplot, interspecies, or intercluster distance matrices yielded a dissimilarity index for each plot, species or cluster, respectively (Bray and Curtis, 1957). The plot, species or cluster with the largest dissimilarity index was the one which provided the greatest separation of the others in the ordination field.

IV. Soil Classification

Two soil pits (1 m^2) were dug and the solum was classified into the appropriate Order and notes on the profiles were recorded. One soil pit was located at the center of the island while the other was located on the north slope at the mesic extremities of the *Salix* spp. Both soil pits were located near transect number 10 (Figure 3). Soil probings (2.5x25 cm) were taken at each island study plot to determine the extent of horizon development.

RESULTS

I. Gradient Study Unit

A. Ordinal Classification

The raw data matrix of the gradient study unit was of the order 74 plots by 64 species. During ordinal classification, 56 plots were arranged into eleven appropriate clusters. The raw data matrix has been presented in Appendix 1 showing the dominant and sub-dominant species which defined each cluster.

The isolated single plot clusters had quantitative species combinations unlike any other plot. The species combinations which isolated these plots have been presented in Appendix 2.

Orthogonal ordination presented the relative proximity of each cluster in three-dimensional Euclidean space. Orthogonal plot ordination produced large discontinuities among groups of clusters (Figure 6). Four associations were defined from clusters which were in close proximity in the Euclidean space. These associations with their member clusters were:

(a) The shoreline association;

(i) *Cirsium arvense* cluster.

(b) The low-moor association;

(i) *Calamagrostis neglecta* cluster,

(ii) "Ecotonal" cluster,

(iii) *Calamagrostis neglecta* - *Carex atherodes* cluster, and

(iv) *Carex atherodes* cluster.

(c) The woodland association;

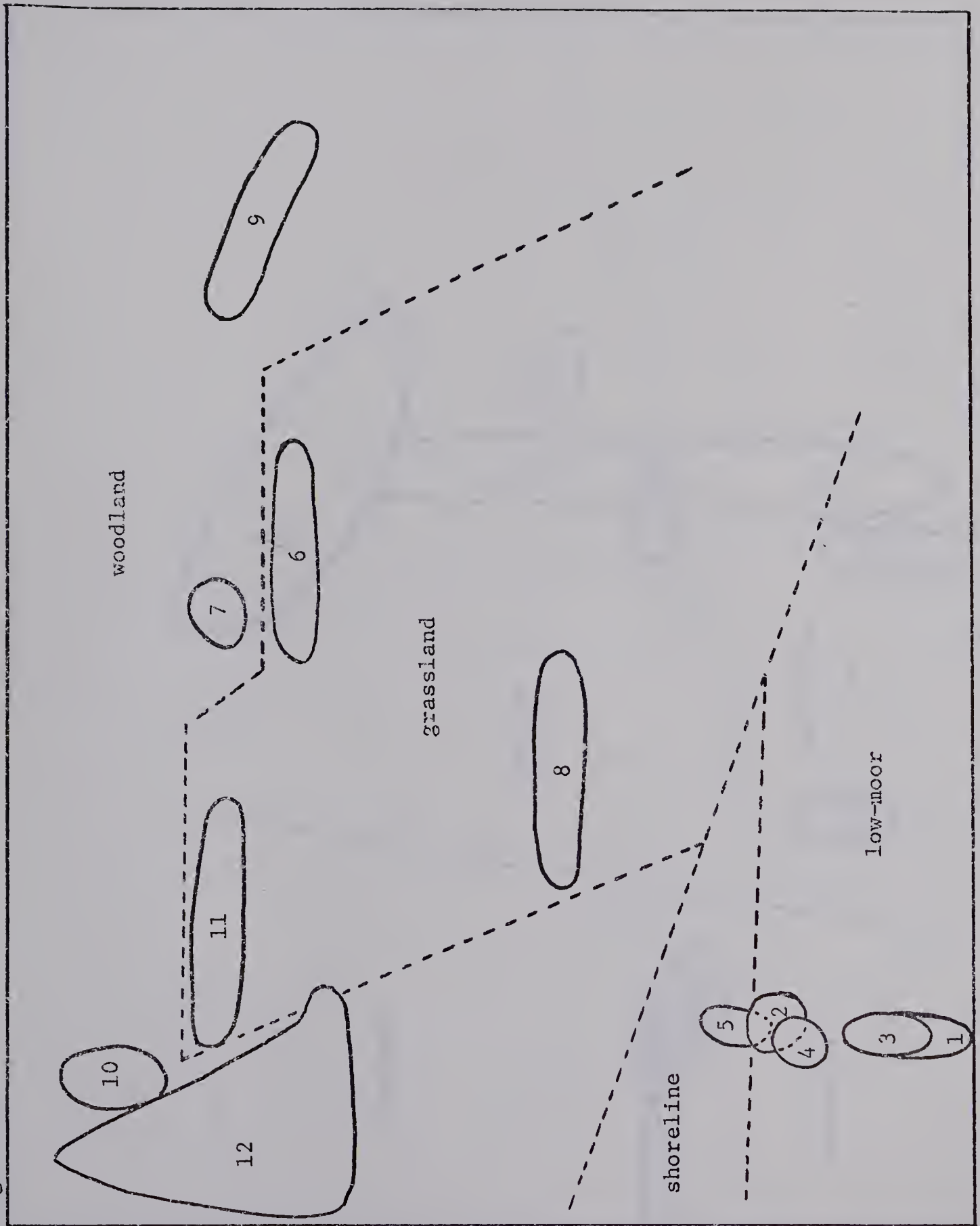
(i) *Poa pratensis* - *Salix bebbiana* var. *perrostrata* cluster,

Figure 6. The three-dimensional orthogonal plot ordination of the replicated clusters in the gradient study unit.

- A. on the XY plane.
- B. on the XZ plane.
- C. on the YZ plane.

CODE	CLUSTER	EUCLIDEAN SPACE EXPLAINED
1	<i>Calamagrostis neglecta</i>	
2	"Ecotonal"	34%
3	<i>Calamagrostis neglecta</i> - <i>Carex atherodes</i>	16%
4	<i>Carex atherodes</i>	12%
5	<i>Cirsium arvense</i>	<u>62%</u>
6	<i>Poa pratensis</i> / <i>Melilotus alba</i>	
7	<i>Poa pratensis</i> - <i>Salix bebbiana</i> var. <i>perrostrata</i>	
8	<i>Melilotus alba</i>	
9	<i>Poa pratensis</i> / <i>Salix bebbiana</i> var. <i>perrostrata</i> - <i>Melilotus alba</i>	
10	<i>Poa pratensis</i> - <i>Populus tremuloides</i> - <i>Populus balsamifera</i>	
11	<i>Poa pratensis</i>	
12	<i>Populus tremuloides</i> - <i>Poa pratensis</i>	
AXIS		
X		34%
Y		16%
Z		<u>12%</u>
Total		62%

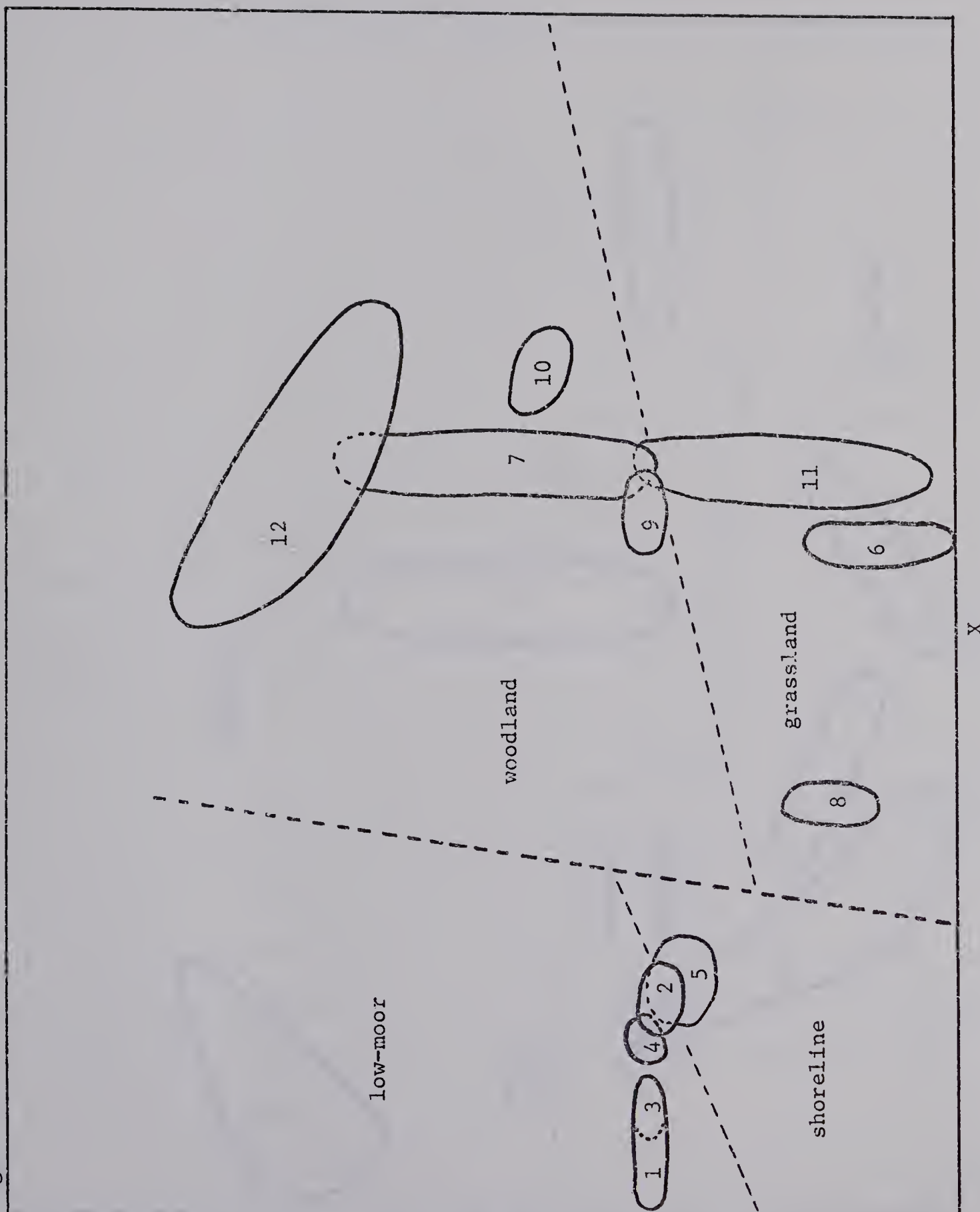
Figure 6A



X

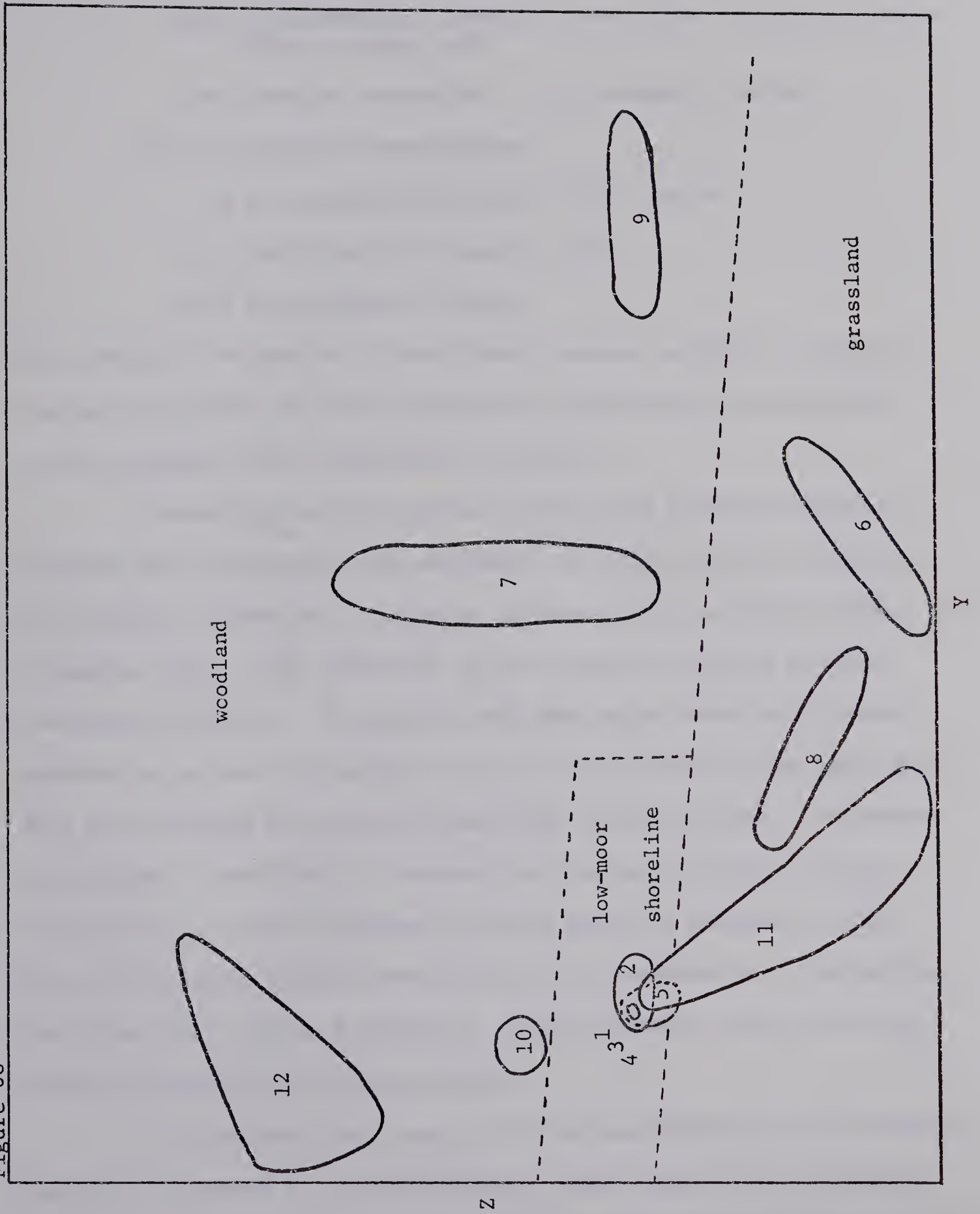
Y

Figure 6B



Z

Figure 6C



- (ii) *Poa pratensis*/*Salix bebbiana* var. *perrostrata* - *Melilotus alba* cluster,
 - (iii) *Poa pratensis* - *Populus tremuloides* - *Populus balsamifera* cluster, and
 - (iv) *Populus tremuloides* - *Poa pratensis* cluster.
- (d) The grassland association;
- (i) *Poa pratensis*/*Melilotus alba* cluster,
 - (ii) *Melilotus alba* cluster, and
 - (iii) *Poa pratensis* cluster.

The orthogonal ordination of the cluster centers in Figure 7 produced cluster proximities in three-dimensional space which were comparable to the orthogonal plot ordination in Figure 6.

An analysis of the species found in the gradient study unit revealed that few species were dominants as defined by the following four species statistics: frequency, presence cover, mean cover and prominence index. The statistics of the important species has been presented in Table 1. The species with the larger mean cover values appeared to be most influential in the classification of the study unit. This was confirmed by inverse ordination classification. The inverse ordination classification isolated ten species which were acting independently. These independent species were *Poa pratensis*, *Calamagrostis neglecta*, *Populus tremuloides*, *Salix bebbiana* var. *perrostrata*, *Melilotus alba*, *Populus balsamifera*, *Cirsium arvense*, *Carex atherodes*, *Sonchus arvensis* and *Salix petiolaris*.

Poa pratensis was found to be the most dissimilar (independent) species as measured by the dissimilarity index (Table 2). The dissimilarity index was highly correlated with presence cover, mean cover and prominence index (Table 3). *Calamagrostis neglecta*, *Populus tremuloides*

Figure 7. The three-dimensional orthogonal cluster ordination of the replicated clusters in the gradient study unit.

- A. on the XY plane.
- B. on the XZ plane.
- C. on the YZ plane.

CODE	CLUSTER	EUCLIDEAN SPACE EXPLAINED
1	<i>Calamagrostis neglecta</i>	
2	"Ecotonal"	28%
3	<i>Calamagrostis neglecta</i> - <i>Carex atherodes</i>	15%
4	<i>Carex atherodes</i>	14%
5	<i>Cirsium arvense</i>	<u>14%</u>
6	<i>Poa pratensis</i> / <i>Melilotus alba</i>	
7	<i>Poa pratensis</i> - <i>Salix bebbiana</i> var. <i>perrostrata</i>	
8	<i>Melilotus alba</i>	
9	<i>Poa pratensis</i> / <i>Salix bebbiana</i> var. <i>perrostrata</i> - <i>Melilotus alba</i>	
10	<i>Poa pratensis</i> - <i>Populus tremuloides</i> - <i>Populus balsamifera</i>	
11	<i>Poa pratensis</i>	
12	<i>Populus tremuloides</i> - <i>Poa pratensis</i>	
AXIS		
X		28%
Y		15%
Z		<u>14%</u>
Total		57%

Figure 7A

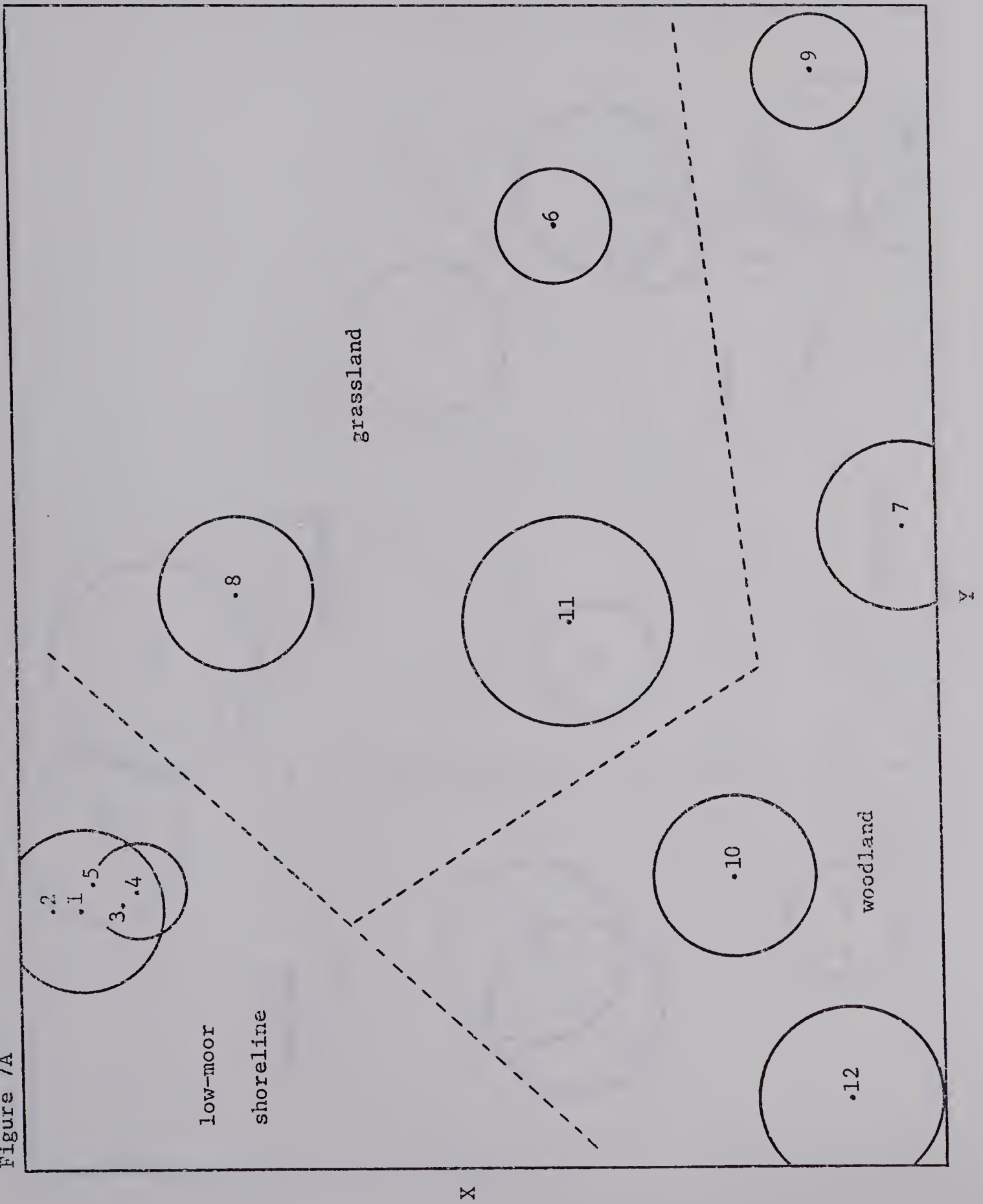
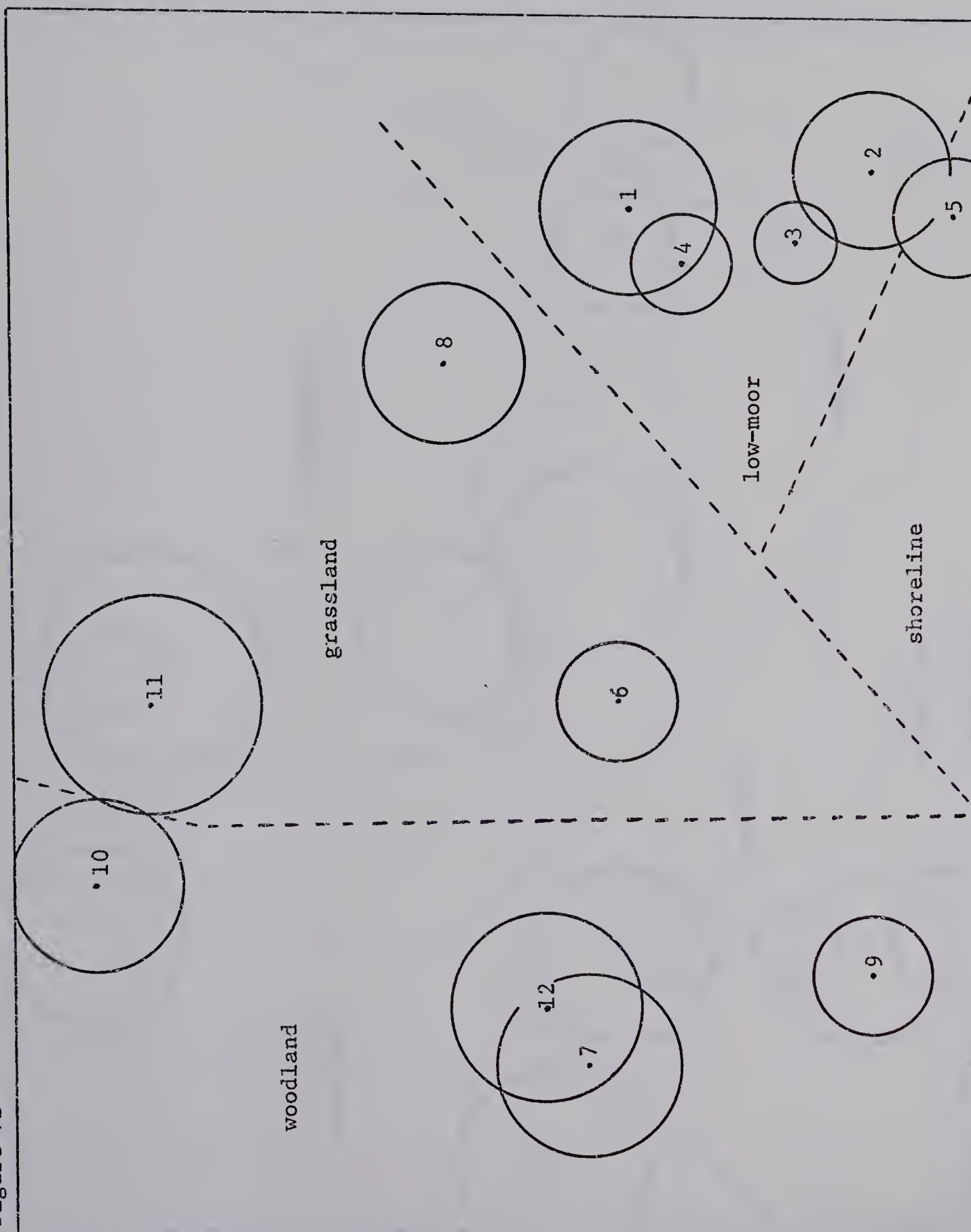


Figure 7B



X

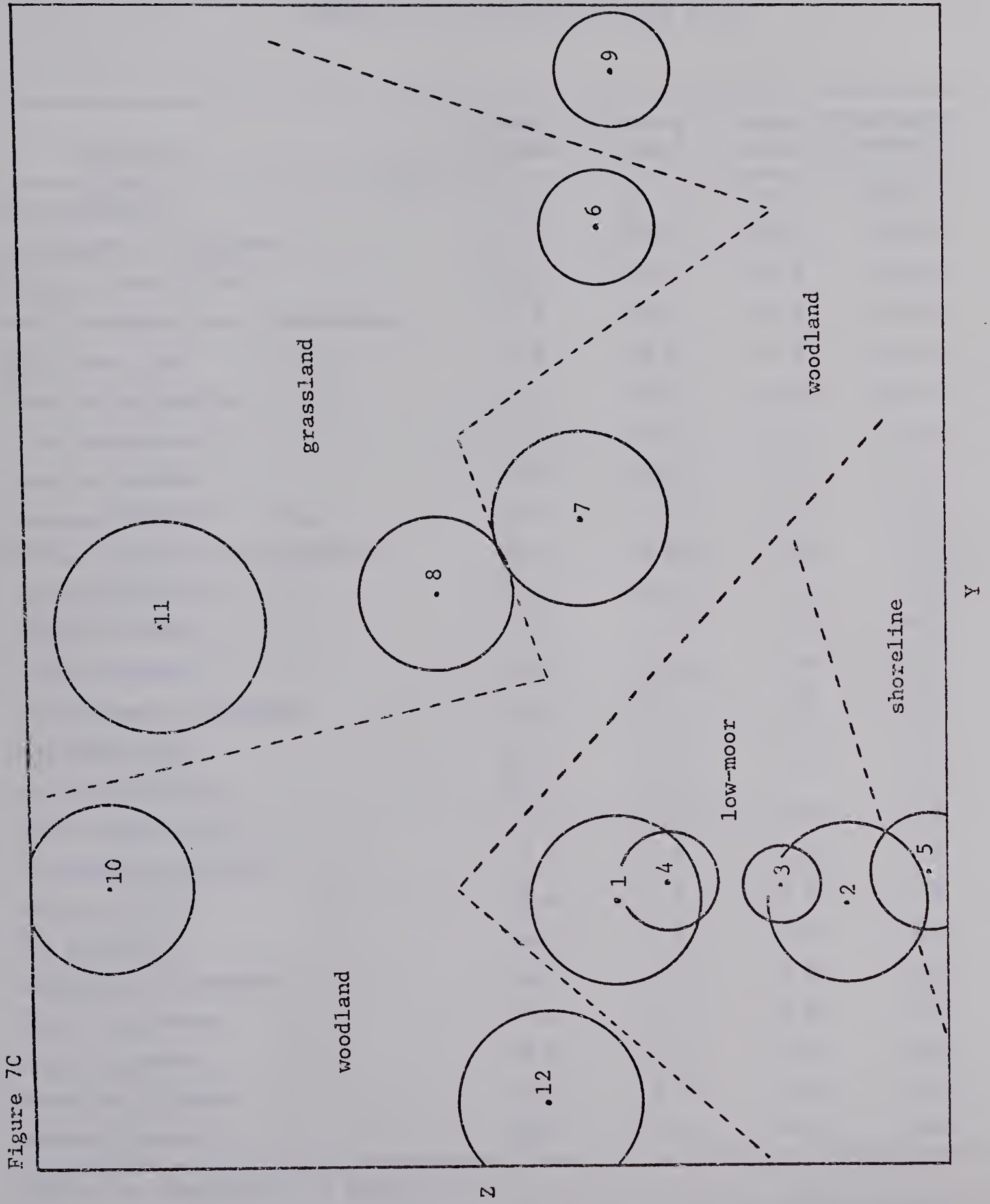


Table 1. Statistics defining the dominant species in the gradient study unit.

Species	Freq. ¹ Percent	Presence Cover ¹	Mean Cover ¹	Prominence Index ¹
<i>Poa pratensis</i> ²	55.4	53.6	29.7	219.8
<i>Calamagrostis neglecta</i>	51.4	28.0	14.4	102.7
<i>Populus tremuloides</i>	24.3	56.1	13.6	76.6
<i>Salix bebbiana</i> var. <i>perrostrata</i>	32.4	35.9	11.6	66.1
<i>Melilotus alba</i>	29.7	30.1	8.9	49.0
<i>Populus balsamifera</i>	21.6	30.3	6.6	30.1
<i>Cirsium arvense</i>	59.5	9.7	5.7	43.9
<i>Carex atherodes</i> ³	44.6	11.1	5.0	33.5
<i>Sonchus arvensis</i>	62.2	4.1	2.5	19.8
<i>Mentha arvensis</i> var. <i>villosa</i>	35.1	5.8	2.0	11.8
<i>Salix petiolaris</i>	13.5	11.5	1.6	5.9
<i>Scirpus validus</i>	35.1	4.4	1.5	8.8
<i>Urtica gracilis</i>	28.4	3.6	1.0	5.3
<i>Calamagrostis inexpansa</i>	36.5	2.6	1.0	6.0
<i>Taraxacum</i> spp.	52.7	1.4	0.7	5.1
<i>Lactuca pulchella</i>	21.6	3.2	0.7	3.2
<i>Carex praegracilis</i>	10.8	5.9	0.6	2.0
<i>Astragalus agrestis</i>	8.1	7.7	0.6	1.1
<i>Juncus balticus</i>	32.4	1.7	0.6	3.4
<i>Poa palustris</i>	36.5	1.5	0.6	3.6
<i>Scorolochloa festuacea</i>	24.3	1.9	0.4	2.4
<i>Carex lasiocarpa</i>	17.6	2.4	0.4	1.7
<i>Aster hesperius</i>	36.5	0.9	0.3	1.8
<i>Artemisia biennis</i>	16.2	2.0	0.3	1.2
<i>Hordeum jubatum</i>	24.3	1.2	0.3	1.5

¹ Refer to terminology on page 29.

² Predominantly *Poa pratensis* with some *Poa compressa* and *Poa glaucifolia*.

³ Predominantly *Carex atherodes* with some *Carex rostrata*.

Table 2. Dissimilarity indices for the independent species.

Species	Dissimilarity Index ¹
<i>Poa pratensis</i> ²	53.4
<i>Populus tremuloides</i>	37.0
<i>Calamagrostis neglecta</i>	34.4
<i>Salix bebbiana</i> var. <i>perrostrata</i>	33.6
<i>Melilotus alba</i>	28.7
<i>Populus balsamifera</i>	23.8
<i>Cirsium arvense</i>	20.6
<i>Carex atherodes</i> ³	18.6
<i>Salix petiolaris</i>	12.4
<i>Sonchus arvensis</i>	11.2
Other species	≤10.0

¹Refer to terminology on page 30.

²Predominantly *Poa pratensis* with some *Poa compressa* and *Poa glaucifolia*.

³Predominantly *Carex atherodes* with some *Carex rostrata*.

Table 3. The relationship between the dissimilarity index (dependent variable) and the four statistics for the independent species in the gradient study unit.

Species Statistic	Regression Coefficient	Correlation Coefficient
Frequency	0.074±0.260	0.10
Presence Cover	0.635±0.109**	0.90**
Mean Cover	1.516±0.130**	0.97**
Prominence Index	0.198±0.028**	0.92**

**p < 0.01

and *Salix bebbiana* var. *perrostrata* had equivalent dissimilarities.

The ordination of the independent species illustrated the proximity of these species in two-dimensional space (Figure 8). The largest distance was recorded between *Poa pratensis* and *Calamagrostis neglecta*. The ecological amplitude of *Poa pratensis* coincided with the higher elevation, lower moisture section of transect numbers 8 and 10 while the ecological amplitude of *Calamagrostis neglecta* corresponded with the lower elevation, higher moisture section (Figure 9). The ecological amplitudes of the remaining independent species could be placed within the ecological amplitude of *Poa pratensis* or *Calamagrostis neglecta* (Figures 10, 11). *Populus tremuloides*, *Salix bebbiana* var. *perrostrata*, *Melilotus alba*, *Populus balsamifera* and *Salix petiolaris* all fell within the range of *Poa pratensis*. *Cirsium arvensis* and *Carex atherodes* recorded the highest coverage values within the range of *Calamagrostis neglecta*; however, they were also present as a relic within the range of *Poa pratensis*. *Sonchus arvensis* was found to be present along most of transect number 3 (Figure 10) and was found to be prominent in the low-moor and grassland portions of transect number 10 (Figure 11).

B. Statistical Analysis

1. Correlation and regression.

Simple correlation coefficients between variables calculated from the data recorded for each of the 70 plots were presented in Table 4. Variables showing significant correlations with annual herbage weight were grass and grass-like weight, forb weight, total herbage coverage, tree density and pH. Variables correlated with grass and grass-like weight were annual herbage weight, tree density, percent

Figure 8. The two-dimensional ordination of the independent species in the gradient study unit.

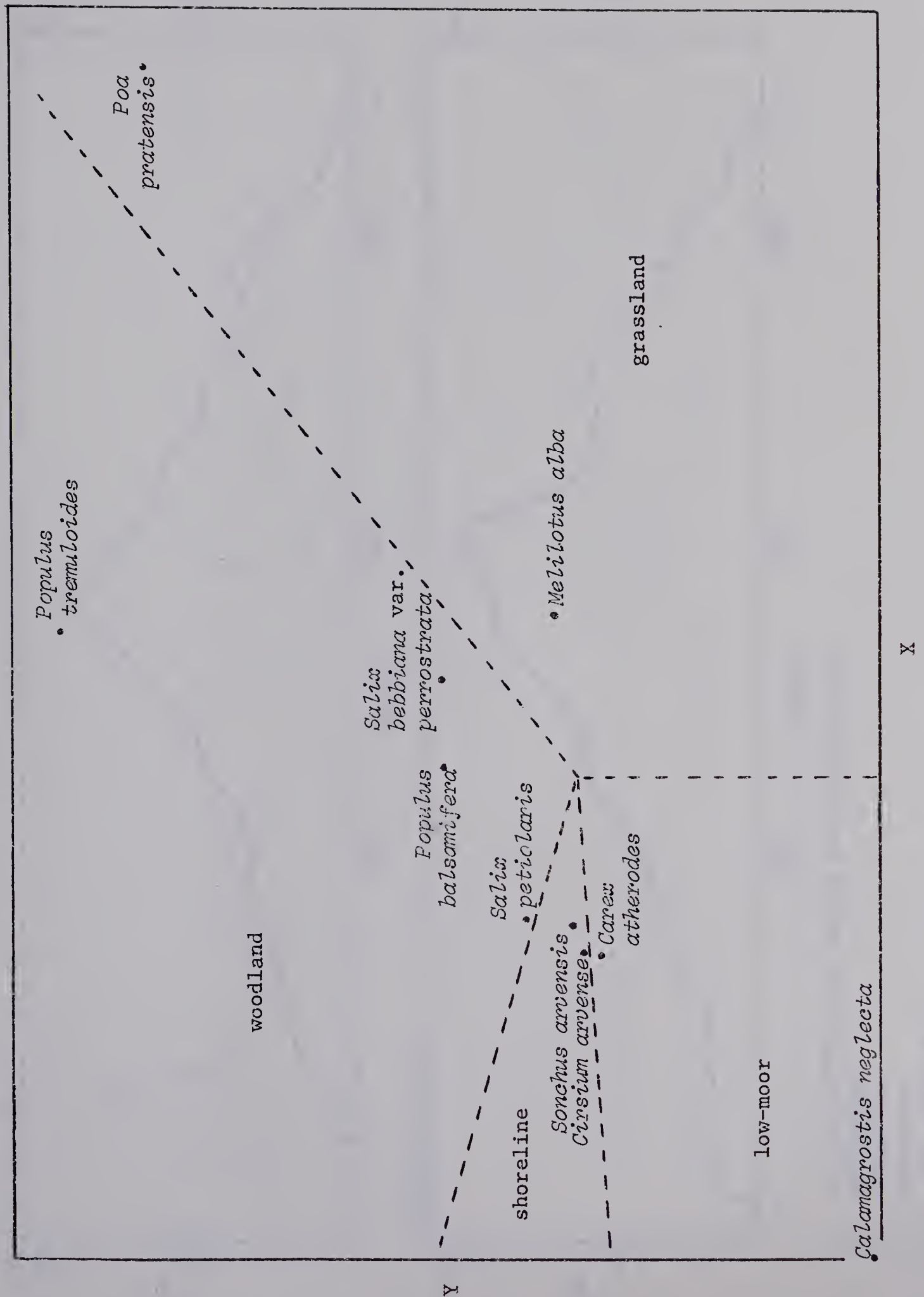
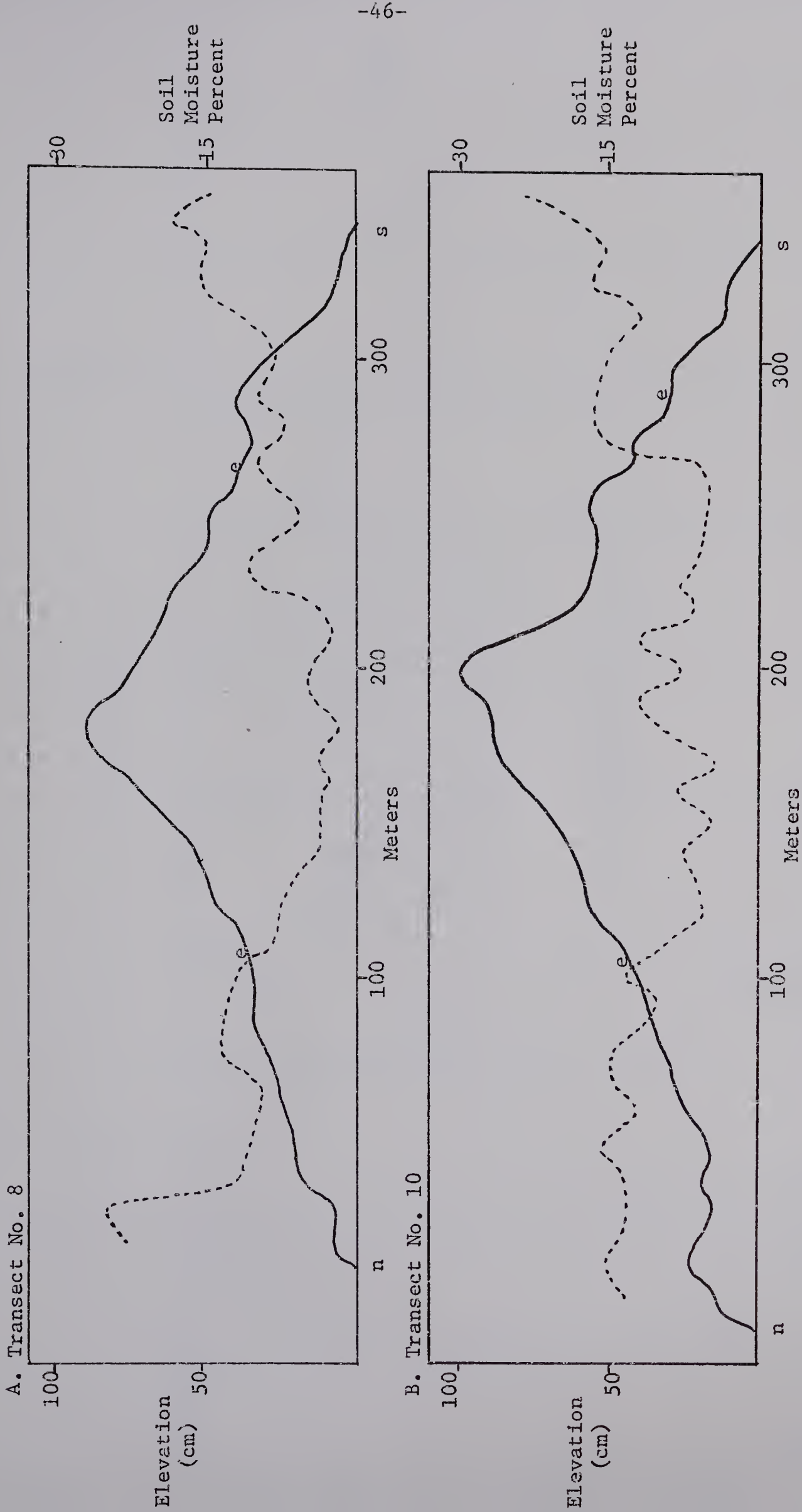


Figure 9. Soil moisture and elevation relationships for the two gradient transects.



e ecotone between the upland and lowland zones
n northshore
s southshore
— elevation
--- soil moisture %

Figure 10. The ecological amplitude of each independent species along transect number 8.

CODE	SPECIES
Popr	<i>Poa pratensis</i> ¹
Potr	<i>Populus tremuloides</i>
Sabe	<i>Salix bebbiana</i> var. <i>perrostrata</i>
Meal	<i>Melilotus alba</i>
Poba	<i>Populus balsamifera</i>
Sape	<i>Salix petiolaris</i>
Cane	<i>Calamagrostis neglecta</i>
Ciar	<i>Cirsium arvense</i>
Caat	<i>Carex atherodes</i> ²
Soar	<i>Sonchus arvensis</i>

n - northshore

s - southshore

t - highest elevation

¹Predominantly *Poa pratensis* with some *Poa compressa* and *Poa glaucifolia*.

²Predominantly *Carex atherodes* with some *Carex rostrata*.

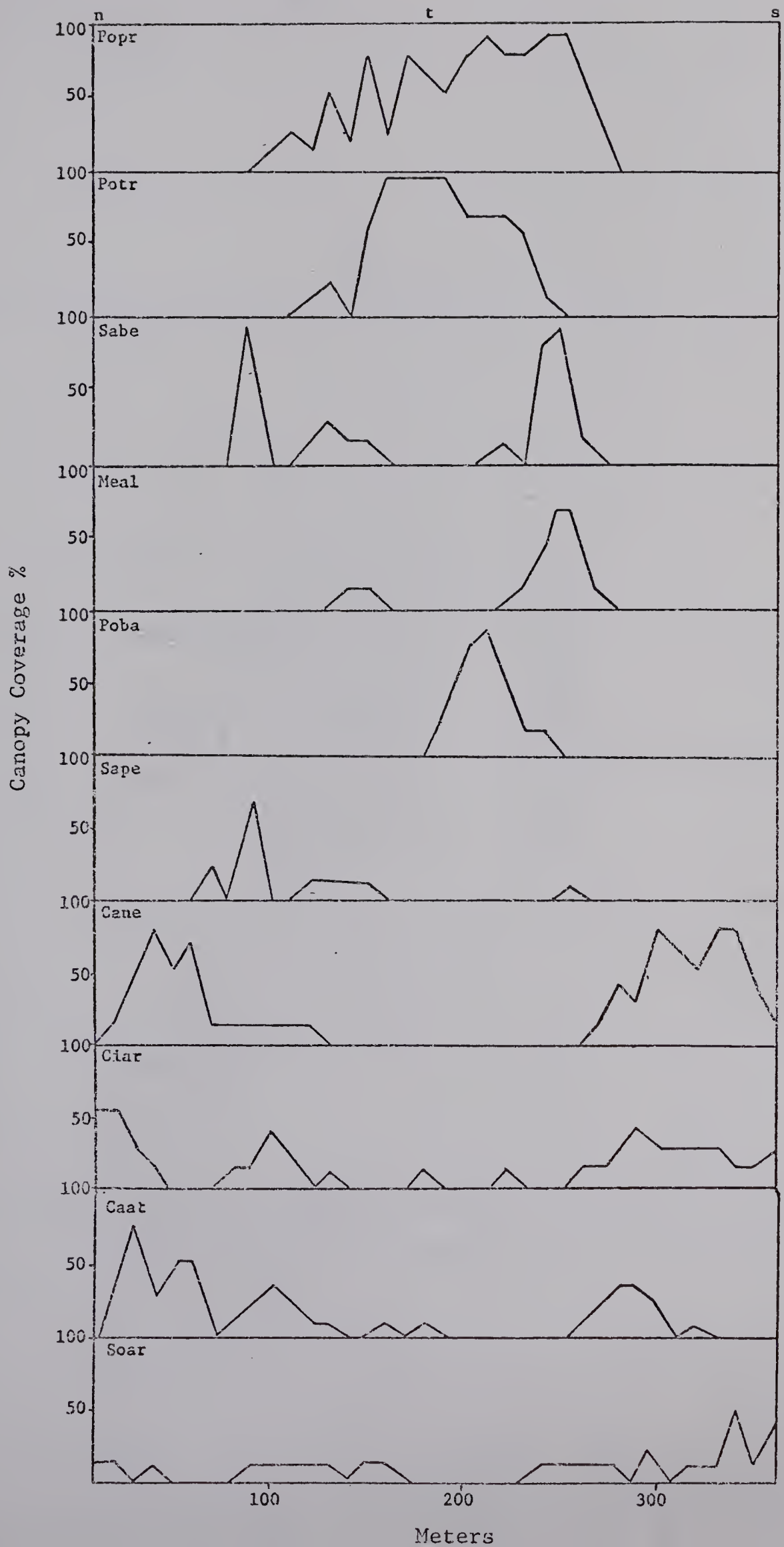


Figure 11. The ecological amplitude of each independent species along transect number 10.

CODE	SPECIES
Popr	<i>Poa pratensis</i> ¹
Potr	<i>Populus tremuloides</i>
Sabe	<i>Salix bebbiana</i> var. <i>perrostrata</i>
Meal	<i>Melilotus alba</i>
Poba	<i>Populus balsamifera</i>
Sape	<i>Salix petiolaris</i>
Cane	<i>Calamagrostis neglecta</i>
Ciar	<i>Cirsium arvense</i>
Caat	<i>Carex atherodes</i> ²
Soar	<i>Sonchus arvense</i>

n - northshore

s - southshore

t - highest elevation

¹Predominantly *Poa pratensis* with some *Poa compressa* and *Poa glaucifolia*.

²Predominantly *Carex atherodes* with some *Carex rostrata*.

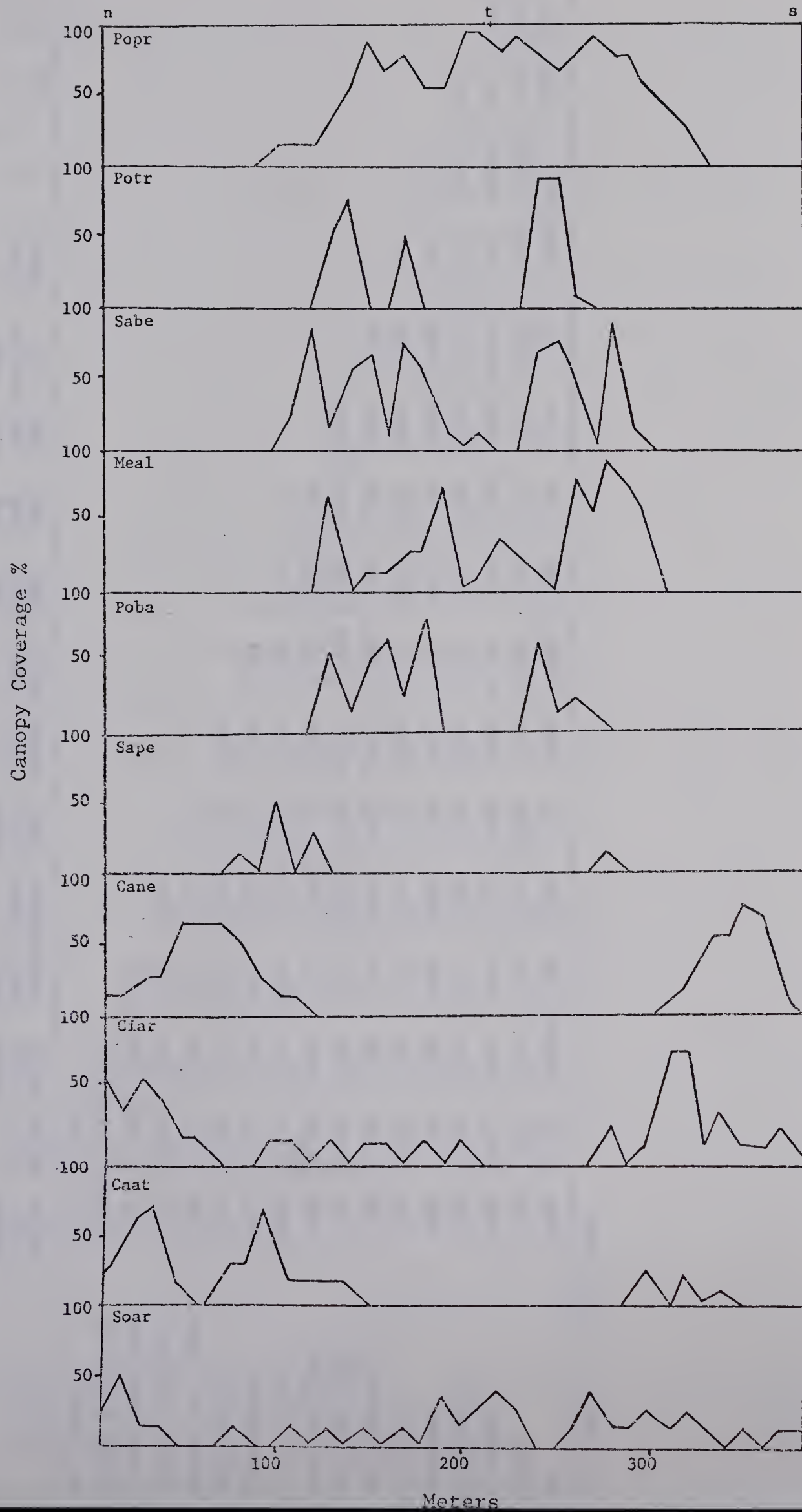


Table 4. Correlation coefficients (r) matrix for all the variables in the gradient study unit as derived from 70 plot observations.

Variable	Grass & Grass-like Weight	Forb Weight	Annual Herb. Weight	Total Herb. Cover	Species Richness	Organic Soil Depth	Shrub Density	Tree Density	June Soil Temp.	July Soil Temp.	Aug. Soil Temp.	Soil Moisture %	Elevation	N	P	K	Na
Forb Weight	-.165	1.000															
Annual Herbage Wt.	0.582**	0.706**	1.000														
Total Herbage Cover	-.129	0.430**	0.263*	1.000													
Species Richness	-.130	0.244	0.107	0.181	1.000												
Organic Soil Depth	0.134	0.043	0.131	-.187	-.135	1.000											
Shrub Density	-.266	-.062	-.213	0.115	0.263*	-.229	1.000										
Tree Density	-.437**	-.086	-.384**	0.183	-.283*	-.231	0.040	1.000									
June Soil Temp.	0.005	0.194	0.164	0.232	0.374**	-.235	0.225	-.190	1.000								
July Soil Temp.	-.200	0.208	0.029	0.110	0.455**	-.092	0.243	-.265*	0.751**	1.000							
Aug. Soil Temp.	-.010	0.043	0.028	-.115	0.299*	0.014	0.117	-.364**	0.780**	0.740**	1.000						
Soil Moisture %	0.395**	-.090	0.208	-.344**	0.048	0.141	-.245	-.488**	-.265*	-.092	-.054	1.000					
Elevation	-.250	0.084	-.109	-.172	-.245	0.035	0.063	0.140	-.170	0.002	-.019	-.169	1.000				
Nitrogen	-.034	0.220	0.157	-.025	0.031	0.187	-.137	-.140	-.417**	-.246	-.272*	0.389**	-.003	1.000			
Phosphorous	-.320*	-.020	-.246	0.111	-.123	-.033	0.066	0.240	0.208	0.039	0.186	-.417**	0.165	-.090	1.000		
Potassium	0.025	0.007	0.023	-.240	-.067	0.080	-.041	0.078	-.436**	-.369**	-.379**	0.404**	-.185	0.484**	-.177	1.000	
Sodium	0.424**	-.081	0.237	-.339**	-.089	0.076	-.169	-.310*	-.298*	-.263*	-.186	0.678**	-.292*	0.403**	-.382**	0.595**	1.000
pH	0.413	0.210	0.471**	0.196	0.149	-.059	-.096	-.402**	0.248	0.102	0.125	-.373**	-.472**	0.174	-.412**	0.117	0.455**

*P < 0.05

**P < 0.01

moisture, phosphorous, sodium and pH. Annual herbage weight and total herbage cover were the only variables significantly correlated with the forb weight. Sodium and percent moisture were found to have the most significant correlations while the organic soil depth was not significantly correlated with any variable.

The calculation of regression of independent variables (coverage, environmental and edaphic) on the dependent variable, annual herbage weight, gave the equation $Y = -61.14 + 0.16X_1 - 4.00X_2 + 13.04X_3$ where Y = annual herbage weight, X_1 = total herbage cover (forced variable), X_2 = tree density and X_3 = pH. This regression equation and the regression coefficients were significant at the 1% level ($R^2=0.328$).

Using only the 12 cluster means as observations, the correlation coefficients between the herbage production, environmental and edaphic variables were determined (Table 5). When 30 randomly selected pairs of correlation coefficients were selected from Tables 4 and 5, it was found that a high correlation ($r=0.711$, $b=1.08$, $P < 0.01$) existed between the correlation coefficients of the two tables. Since the removal of the within-cluster variation did not significantly change the correlation between the variables, the cluster means were used as the values of each variable.

The regression analysis using Grobbs (1970) for each orthogonal axis was derived from paired observations among the cluster means for each variable and the cluster center position on each axis. The orthogonal X-axis of the cluster ordination was defined by elevation, shrub density and tree density. The resulting equation was $Y = 188.21 - 1.42X_1 - 4.62X_2 - 8.77X_3$ where Y = the orthogonal X-axis, X_1 = elevation ($t=-5.26$, $P < 0.01$), X_2 = shrub density ($t=-5.39$, $P < 0.01$) and X_3 = tree density ($t=-3.65$, $P < 0.01$).

Table 5. Correlation coefficients (r) matrix for all the variables in the gradient study unit as derived from 12 cluster means.

Variable	Grass & Grass-like Weight	Forb Weight	Annual Herb. Weight	Total Herb. Cover	Species Richness	Organic Soil Depth	Shrub Density	Tree Density	June Soil Temp.	July Soil Temp.	Aug. Soil Temp.	Soil Moisture %	Elevation	N	P	K	Na
Forb Weight	-0.344	1.000															
Annual Herbage Wt.	0.349	0.757**	1.000														
Total Herbage Cover	-0.154	0.683*	0.557*	1.000													
Species Richness	-0.386	0.620*	0.363	0.275	1.000												
Organic Soil Depth	0.540	-0.182	0.180	-0.208	-0.426	1.000											
Shrub Density	-0.259	-0.145	-0.332	0.129	0.355	-0.492	1.000										
Tree Density	-0.477	-0.045	-0.382	0.190	-0.335	-0.469	0.121	1.000									
June Soil Temp.	-0.029	0.553*	0.546	0.487	0.381	-0.337	0.157	-0.191	1.000								
July Soil Temp.	0.011	0.526	0.547	0.231	0.480	-0.267	0.154	-0.377	0.900**	1.000							
Aug. Soil Temp.	0.169	0.282	0.420	0.028	0.379	-0.084	0.007	-0.610*	0.808**	0.892**	1.000						
Soil Moisture %	0.478	0.016	0.355	-0.279	0.277	0.472	-0.284	-0.618*	-0.388	-0.152	-0.042	1.000					
Elevation	-0.631*	0.012	-0.422	0.263	-0.078	-0.584*	0.223	0.587*	0.232	0.027	-0.017	-0.826**	1.000				
Nitrogen	-0.167	-0.097	-0.201	-0.220	0.117	0.088	-0.380	-0.076	-0.579*	-0.600*	-0.397	0.443	-0.180	1.000			
Phosphorous	-0.406	-0.269	-0.747	-0.119	-0.335	-0.249	-0.141	0.370	0.034	-0.127	0.051	-0.663*	0.815**	0.031	1.000		
Potassium	-0.182	-0.324	-0.434	-0.503	0.185	-0.100	0.190	0.041	-0.683*	-0.510	-0.514	0.465	-0.310	0.622*	-0.330	1.000	
Sodium	0.648*	-0.271	0.190	0.231	-0.049	0.423	-0.279	-0.508	-0.364	-0.175	-0.060	0.798**	-0.882**	0.368	-0.648*	-0.510	1.000
pH	0.244	0.462	0.643*	0.028	0.550	-0.039	-0.027	-0.479	0.462	0.390	0.462	0.350	-0.382	0.196	-0.426	-0.123	0.243

*P < 0.05

**P < 0.01

The squared multiple correlation coefficient (R^2) was 0.951 and the equation was highly significant ($F=51.5$, $P < 0.01$). Other variables correlated with the X-axis have been presented in Table 6.

The orthogonal Y-axis was defined by the equation $Y = 249.38 + 48.76X_1 + 52.59X_2 - 0.78X_3$ where Y = the orthogonal Y-axis, X_1 = June soil temperature ($t=7.01$, $P < 0.01$), X_2 = August soil temperature ($t=-4.56$, $P < 0.01$) and X_3 = phosphorous ($t=-.211$, $P < 0.05$). The regression equation was highly significant ($F=19.0$, $P < 0.01$) and $R^2 = 0.877$. Other variables correlated with the Y-axis have been presented in Table 6.

The orthogonal Z-axis was defined by the least number of variables. The resulting equation was $Y = -205.16 + 2.26X_1 + 30.72X_2$ where Y = the orthogonal Z-axis, X_1 = phosphorous ($t=4.67$, $P < 0.01$) and X_2 = pH ($t=1.70$). The R^2 value was 0.708 and F was equal to 10.9 ($P < 0.01$). Other variables correlated with the Z-axis have been presented in Table 6.

2. One-way analysis of variance.

One-way analysis of variance among the clusters of the gradient study unit for the herbage production, environmental and edaphic variables have been presented in Tables 7, 8 and 9, respectively. Significant F values were found for each variable except nitrogen and potassium confirming that statistical differences existed among clusters. The variables in descending order of significance were tree density, soil moisture percent, elevation, shrub density, grass and grass-like weight, sodium, annual herbage weight, forb weight, June soil temperature, July soil temperature, species richness, soil pH, depth of organic soil, phosphorous, and August soil temperature (Tables 7, 8, 9).

The one-way analysis of variance among associations for the

Table 6. Correlation coefficients (r) between the cluster position on each orthogonal axis and the cluster means of the herbage production, environmental and edaphic variables in the gradient study unit.

Variable	X-axis	Y-axis	Z-axis
Grass and grass-like wt.	0.57*	-.04	-.19
Forb weight	0.06	0.59*	-.29
Annual herbage weight	0.45	0.57*	-.41
Species richness	0.07	0.24	-.18
June soil temperature	-.14	0.69**	0.24
July soil temperature	0.10	0.49	0.07
Aug. soil temperature	0.28	0.22	0.29
Soil moisture %	0.81**	-.35	-.57*
Elevation	-.83**	0.20	0.69**
Shrub density	-.59*	0.30	0.05
Tree density	-.72**	0.20	0.06
Depth of organic soil	0.62*	-.29	-.37
Nitrogen	0.30	-.52	0.05
Phosphorous	-.46	-.26	0.78**
Potassium	0.11	-.47	-.28
Sodium	0.77**	-.39	-.45
pH	0.36	0.40	-.60*

*P < 0.05

**P < 0.01

Table 7. A one-way analysis of variance of each herbage production variable for the replicated clusters in the gradient study unit.¹

Cluster	No. of Plots	Grass & Grass-like Weight (kg/ha D.M.)	Forb Weight (kg/ha D.M.)	Annual Herbage Weight (kg/ha D.M.)	Species Richness (no./plot)
<i>Calamagrostis neglecta</i>	13	2560 ^{a2}	130 ^{bc}	2790 ^{ab}	9.6 ^{bcd}
"Ecotonal"	13	1475 ^{abc}	515 ^{ab}	2235 ^{ab}	10.0 ^{bcd}
<i>Calamagrostis neglecta</i> - <i>Carex atherodes</i>	2	2400 ^{ab}	150 ^{bc}	2550 ^{ab}	6.5 ^{cd}
<i>Carex atherodes</i>	2	2615 ^a	50 ^c	2660 ^{ab}	6.0 ^d
<i>Cirsium arvense</i>	2	595 ^{cde}	2715 ^a	3415 ^{ab}	16.9 ^a
<i>Poa pratensis</i> / <i>Melilotus alba</i>	2	1240 ^{abcd}	2505 ^a	3850 ^a	10.5 ^{abc}
<i>Poa pratensis</i> - <i>Salix bebbiana</i> var. <i>perrostrata</i>	3	995 ^{bcd}	260 ^{bc}	1255 ^{bc}	14.3 ^{ab}
<i>Melilotus alba</i>	3	1110 ^{abcd}	2590 ^a	3815 ^a	13.5 ^{ab}
<i>Poa pratensis</i> / <i>Salix bebbiana</i> var. <i>perrostrata</i> - <i>Melilotus alba</i>	2	1360 ^{abc}	2105 ^a	3615 ^a	9.0 ^{bcd}
<i>Poa pratensis</i> - <i>Populus tremuloides</i> - <i>Populus balsamifera</i>	3	525 ^{de}	105 ^{bc}	655 ^{cd}	7.3 ^{cd}
<i>Poa pratensis</i>	7	1760 ^{ab}	620 ^{ab}	2600 ^{ab}	10.7 ^{abc}
<i>Populus tremuloides</i> - <i>Poa pratensis</i>	4	330 ^e	155 ^{bc}	460 ^d	6.9 ^{cd}
Grand Mean	56	1400±105	380±185	2195±105	9.7±1.4
F Value		8.07***	4.89***	5.45***	3.51***

¹Raw data was transformed to the logarithmic scale and the means presented were geometric.

²Numbers with the same superscript are not significantly different at P < 0.05 level (Duncan's New Multiple Range Test).

***P < 0.005

Table 8. A one-way analysis of variance of each environmental variable for the replicated clusters in the gradient study unit.¹

Cluster	No. of Plots	Soil Temp. (C° at 15 cm)			Soil Moisture %	Elevation (cm above lake level)	Shrub Density	Tree Density
		June	July	August				
<i>Calamagrostis neglecta</i>	13	13.2 ^{bcd}	12.6 ^{bc}	15.5 ^{abc}	12.0 ^{ab}	15.2 ^d	0.0 ^d	0.0 ^d
"Ecotonal"	13	13.1 ^{bcd}	13.4 ^{bc}	16.0 ^{abc}	11.8 ^{ab}	21.3 ^{cd}	0.1 ^{de}	0.0 ^d
<i>Calamagrostis neglecta</i> - <i>Carex atherodes</i>	2	13.2 ^{bcd}	12.7 ^{bc}	15.8 ^{abc}	9.4 ^{abc}	24.4 ^{bcd}	0.0 ^d	0.0 ^d
<i>Carex atherodes</i>	2	11.7 ^e	12.5 ^{bc}	15.0 ^{bc}	12.9 ^{ab}	24.4 ^{bcd}	0.0 ^d	0.0 ^d
<i>Cirsium arvense</i>	2	12.2 ^{cd}	12.5 ^{bc}	15.0 ^{bc}	15.5 ^a	27.4 ^{bcd}	0.0 ^d	0.0 ^d
<i>Poa pratensis</i> /Melilotus alba	2	15.5 ^{ab}	13.7 ^b	16.0 ^{abc}	5.4 ^{de}	45.7 ^{abc}	2.0 ^{bc}	0.0 ^d
<i>Poa pratensis</i> - <i>Salix bebbiana</i> var. <i>perrostrata</i>	3	14.1 ^{abc}	13.5 ^{bc}	15.8 ^{abc}	6.5 ^{cd}	48.8 ^{abc}	18.6 ^a	1.1 ^c
Melilotus alba	3	16.7 ^a	15.3 ^a	17.7 ^a	5.6 ^{cde}	48.8 ^{abc}	0.8 ^{bcd}	0.0 ^d
<i>Poa pratensis</i> /Salix bebbiana var. <i>perrostrata</i> - Melilotus alba	2	14.3 ^{abc}	13.0 ^{bc}	14.7 ^{bc}	5.3 ^{de}	51.8 ^{ab}	3.0 ^b	6.3 ^a
<i>Poa pratensis</i> - <i>Populus tremuloides</i> - <i>Populus balsamifera</i>	3	12.5 ^{cd}	12.0 ^c	15.0 ^{bc}	3.4 ^e	67.0 ^a	1.3 ^{bcd}	3.4 ^b
<i>Poa pratensis</i>	7	14.9 ^{ab}	13.5 ^{bc}	16.7 ^{ab}	7.7 ^{bcd}	70.0 ^a	1.0 ^{bcd}	1.1 ^d
<i>Populus tremuloides</i> - <i>Poa pratensis</i>	4	12.0 ^{cd}	12.1 ^{bc}	14.4 ^c	3.3 ^e	73.2 ^a	2.1 ^b	5.3 ^{ab}
Grand Mean	56	13.5±1.1	13.0±1.1	15.7±1.1	8.6±1.6	33.5±30.5	1.7±2.4	0.4±2.0
F Value		4.22***	3.57***	2.54*	11.74***	10.81***	9.21***	41.64***

¹Raw data was transformed to the logarithmic scale and the means presented were geometric.

²Numbers with the same superscript are not sig. different at P < 0.05 level (Duncan's New Multiple Range Test).

*P < 0.05 ***P < 0.005

Table 9. A one-way analysis of variance of each edaphic variable for the replicated clusters in the gradient study unit.¹

Cluster	No. of Plots	Organic Soil Depth (cm)	Nitrogen (kg/ha)	Phosphorous (kg/ha)	Potassium (kg/ha)	Sodium (kg/ha)	pH
<i>Calamagrostis neglecta</i>	13	1.3 ^{abcd} ²	6.2 ^a	4.9 ^{ab}	568.1 ^a	411.6 ^a	8.3 ^a
"Ecotonal"	13	2.4 ^{abc}	4.1 ^a	4.8 ^{ab}	625.1 ^a	311.5 ^{ab}	7.7 ^a
<i>Calamagrostis neglecta</i> - <i>Carex atherodes</i>	2	3.9 ^a	2.0 ^a	21.3 ^{ab}	372.7 ^a	150.4 ^{abcd}	7.9 ^a
<i>Carex atherodes</i>	2	2.9 ^{ab}	2.8 ^a	4.4 ^{ab}	511.4 ^a	265.8 ^{abc}	7.5 ^a
<i>Cirsium arvense</i>	2	1.7 ^{abc}	8.0 ^a	3.4 ^b	608.0 ^a	181.4 ^{abcd}	8.3 ^a
<i>Poa pratensis</i> / <i>Melilotus alba</i>	2	2.5 ^{abc}	2.0 ^a	11.1 ^{ab}	374.0 ^a	64.6 ^{bcd}	8.0 ^a
<i>Poa pratensis</i> - <i>Salix bebbiana</i> var. <i>perrostrata</i>	3	0.0 ^d	1.1 ^a	7.4 ^{ab}	569.9 ^a	77.9 ^{abcd}	7.9 ^a
<i>Melilotus alba</i>	3	0.3 ^{cd}	0.7 ^a	25.4 ^{ab}	346.0 ^a	55.4 ^{bcd}	8.2 ^a
<i>Poa pratensis</i> / <i>Salix bebbiana</i> var. <i>perrostrata</i> - <i>Melilotus alba</i>	2	0.4 ^{cd}	1.6 ^a	8.1 ^{ab}	446.0 ^a	50.1 ^{bcd}	8.0 ^a
<i>Poa pratensis</i> - <i>Populus tremuloides</i> - <i>Populus balsamifera</i>	3	1.1 ^{abcd}	7.1 ^a	45.4 ^a	533.1 ^a	30.7 ^{de}	7.9 ^a
<i>Poa pratensis</i>	7	1.0 ^{abcd}	3.4 ^a	42.0 ^{ab}	400.9 ^a	41.7 ^{cde}	8.0 ^a
<i>Populus tremuloides</i> - <i>Poa pratensis</i>	4	0.8 ^{bcd}	3.1 ^a	46.4 ^a	517.0 ^a	8.2 ^e	6.6 ^b
Grand Mean	56	1.4±1.8	3.7±2.8	10.8±4.5	515.5±1.7	126.9±4.8	7.9±1.1
F Value		2.77**	1.14	2.74**	1.27	7.52***	3.41***

¹Raw data was transformed to the logarithmic scale and the means presented were geometric.

²Numbers with the same superscript are not sig. different at P < 0.05 level (Duncan's New Multiple Range Test).

P < 0.01 *P < 0.005

herbage production, environmental and edaphic variables have been presented in Tables 10, 11 and 12, respectively. The woodland association was significantly lower in annual herbage weight than the low-moor, shoreline and grassland associations while the grass and grass-like weight of the low-moor and grassland associations were significantly higher than the shoreline and woodland associations (Table 10). The largest forb weight was recorded in the shoreline association; however, this association was not significantly different from the grassland association. The species richness of the shoreline association was significantly greater than the other associations. The temperature of the grassland soil was consistently warmer than the other associations although the woodland association had less soil moisture and occurred at a high elevation (Table 11). Soluble soil nutrients were found to be the lowest in the grassland and woodland associations while phosphorous was the highest (Table 12). The soil pH was found to be significantly lower in the woodland association.

II. Reconnaissance Study Unit

A. Ordinal Classification

The raw data matrix of the reconnaissance study unit was of the order 70 plots by 73 species. Fifty-nine plots were grouped into 11 clusters during ordinal classification while 11 plots were isolated as single plot clusters. Arranging the plots into the appropriate clusters, the raw data matrix was presented in Appendix 3 showing the dominant and sub-dominant species defining each cluster. The isolated single plot clusters contained species combinations which isolated these plots from the remainder. The dominant and sub-dominant species of these

Table 10. A one-way analysis of variance of each herbage production variable for the four associations in the gradient study unit.¹

Association	Grass & Grass-like Weight (kg/ha D.M.)	Forb Weight (kg/ha D.M.)	Annual Herbage Weight (kg/ha D.M.)	Species Richness (no./plot)
Shoreline	598 ^{b²}	2721 ^a	3424 ^a	16.9 ^a
Low-moor	2013 ^a	234 ^c	2510 ^a	9.2 ^b
Woodland	597 ^b	273 ^{bc}	925 ^b	8.8 ^b
Grassland	1485 ^a	1132 ^{ab}	3060 ^a	11.3 ^b
F Value	14.10***	6.41***	10.05***	3.61**

¹ Raw data has been transformed to the logarithmic scale and the means are geometric.

² Numbers with the same superscript are not significantly different at $P < 0.05$ level (Duncan's New Multiple Range Test).

** $P < 0.01$ *** $P < 0.005$

Table 11. A one-way analysis of variance of each environmental variable for the four associations in the gradient study unit.¹

Association	June Soil Temp. (C°)	July Soil Temp. (C°)	Aug. Soil Temp. (C°)	Soil Moisture (%)	Elevation (cm)	Shrub Density (no./plot)	Tree Density (no./plot)
Shoreline	12.2 ^b ₂	12.5 ^b	15.0 ^b	15.5 ^a	28.3 ^b	0.0 ^b	0.0 ^b
Low-moor	13.1 ^b	12.8 ^b	15.7 ^{ab}	11.8 ^a	19.7 ^b	0.0 ^b	0.0 ^b
Woodland	13.0 ^b	12.6 ^b	14.9 ^b	4.3 ^c	60.6 ^a	3.8 ^a	3.5 ^a
Grassland	15.4 ^a	14.0 ^a	16.8 ^a	6.7 ^b	60.3 ^a	1.1 ^b	0.1 ^b
F Value	9.89***	5.90***	6.22***	33.35***	33.68***	16.70***	71.95***

¹Raw data has been transformed to the logarithmic scale and the means are geometric.

²Numbers with the same superscript are not significantly different at P < 0.05 level (Duncan's New Multiple Range Test).

***p < 0.005

Table 12. A one-way analysis of variance of each edaphic variable for the four associations in the gradient study unit.¹

Association	Organic Soil Depth(cm)	Nitrogen (kg/ha)	Phosphorus (kg/ha)	Potassium (kg/ha)	Sodium (kg/ha)	pH
Shoreline	1.7 ^{a2}	7.8 ^a	3.3 ^b	596.6 ^a	177.9 ^a	8.3 ^a
Low-moor	2.0 ^a	4.5 ^a	5.3 ^b	559.2 ^a	325.3 ^a	7.9 ^a
Woodland	0.5 ^b	2.8 ^a	21.9 ^a	517.1 ^a	27.1 ^b	7.4 ^b
Grassland	1.0 ^a	2.2 ^a	29.8 ^a	374.9 ^b	47.3 ^b	8.0 ^a
F Value	4.68***	1.52	6.62***	3.48*	21.84**	2.90*

¹Raw data has been transformed to the logarithmic scale and the means are geometric.

²Numbers with the same superscript are not significantly different at P < 0.05 level (Duncan's New Multiple Range Test).

*P < 0.05 **P < 0.01 ***P < 0.005

plots have been presented in Appendix 4.

Orthogonal ordination presented the relative proximity of each cluster in three-dimensional space. Discontinuities among the 11 clusters were revealed by orthogonal ordination of the plots within each cluster (Figure 12). Relative discontinuities among sets of clusters were also suggested. Four associations were defined from clusters which occurred in close proximity (Figure 12). These associations and their member clusters were:

(a) The shoreline association;

- (i) *Scirpus validus* - *Cirsium arvense* - *Sonchus arvensis* cluster.

(b) The low-moor association;

- (i) *Scolochloa festucacea* cluster, and
- (ii) *Carex atherodes* - *Calamagrostis neglecta* cluster.

(c) The woodland association;

- (i) *Poa pratensis* - *Salix bebbiana* var. *perrostrata* cluster,
- (ii) *Populus tremuloides* - *Poa pratensis*/*Salix bebbiana* var. *perrostrata* cluster, and
- (iii) *Populus tremuloides* - *Poa pratensis* cluster.

(d) The grassland association;

- (i) *Poa pratensis* - *Astragalus canadensis* cluster,
- (ii) *Poa pratensis* - *Melilotus alba* cluster,
- (iii) *Poa pratensis* cluster, and
- (iv) *Poa pratensis* - *Taraxacum* spp. cluster.

The orthogonal ordination of the cluster centers in Figure 13 produced a three-dimensional space which was comparable to the orthogonal plot ordination. The relative proximity of the clusters was maintained

Figure 12. The three-dimensional orthogonal plot ordination of the replicated clusters in the reconnaissance study unit.

- A. on the XY plane.
- B. on the XZ plane.
- C. on the YZ plane.

CODE	CLUSTER
1	<i>Scirpus validus</i> - <i>Cirsium arvense</i> - <i>Sonchus arvensis</i>
2	<i>Scolochloa festuacea</i>
3	<i>Carex atherodes</i> - <i>Calamagrostis neglecta</i>
4	<i>Poa pratensis</i> - <i>Salix bebbiana</i> var. <i>perrostrata</i>
5	<i>Populus tremuloides</i> - <i>Poa pratensis</i> / <i>Salix bebbiana</i> var. <i>perrostrata</i>
6	<i>Populus tremuloides</i> - <i>Poa pratensis</i>
7	<i>Poa pratensis</i> - <i>Astragalus canadensis</i>
8	<i>Poa pratensis</i> - <i>Melilotus alba</i>
9	<i>Poa pratensis</i>
10	<i>Poa pratensis</i> - <i>Taraxacum</i> spp.

AXIS	EUCLIDEAN SPACE EXPLAINED
X	31%
Y	10%
Z	8%
Total	<u>49%</u>

Figure 1.2A

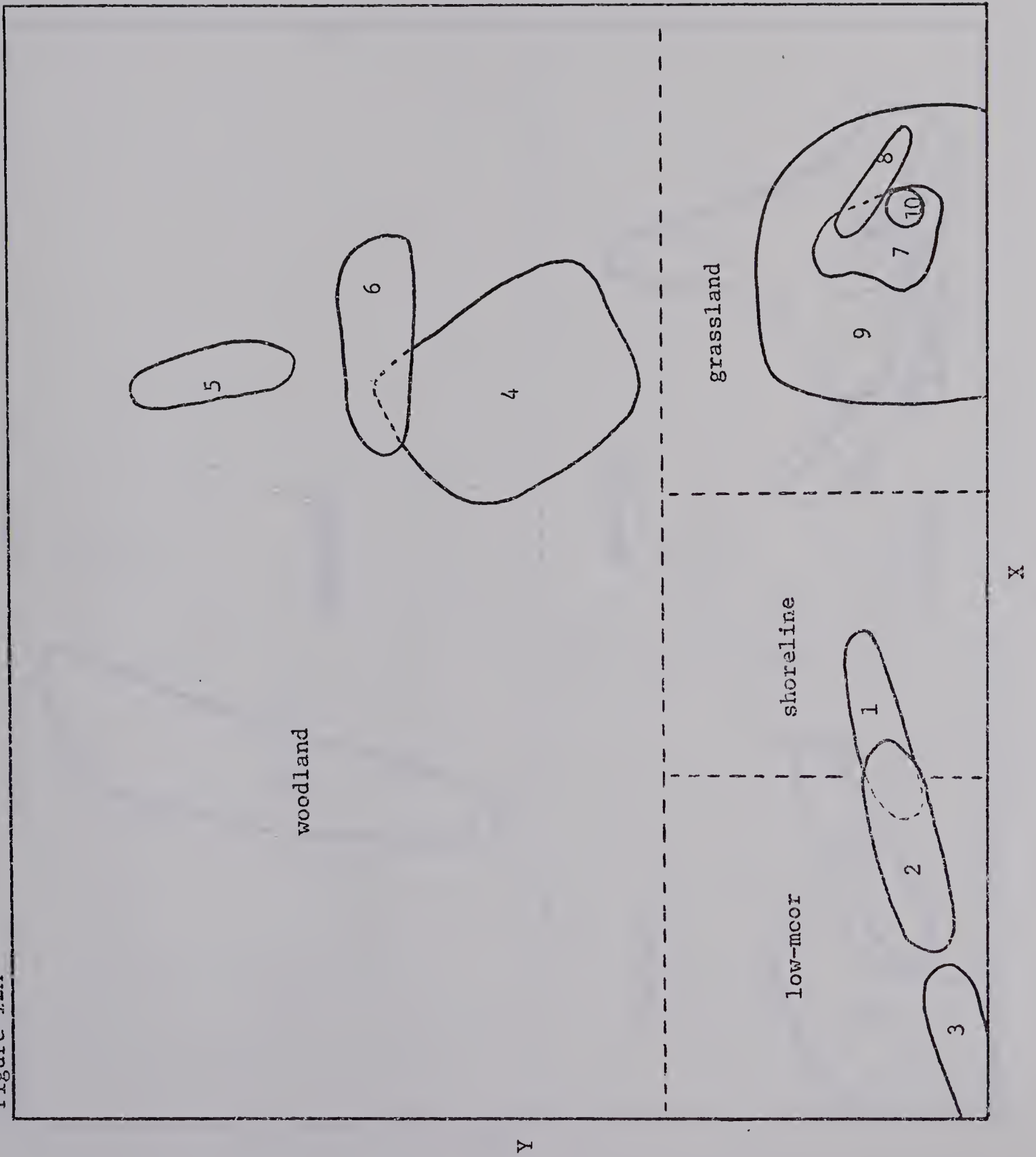


Figure 12B

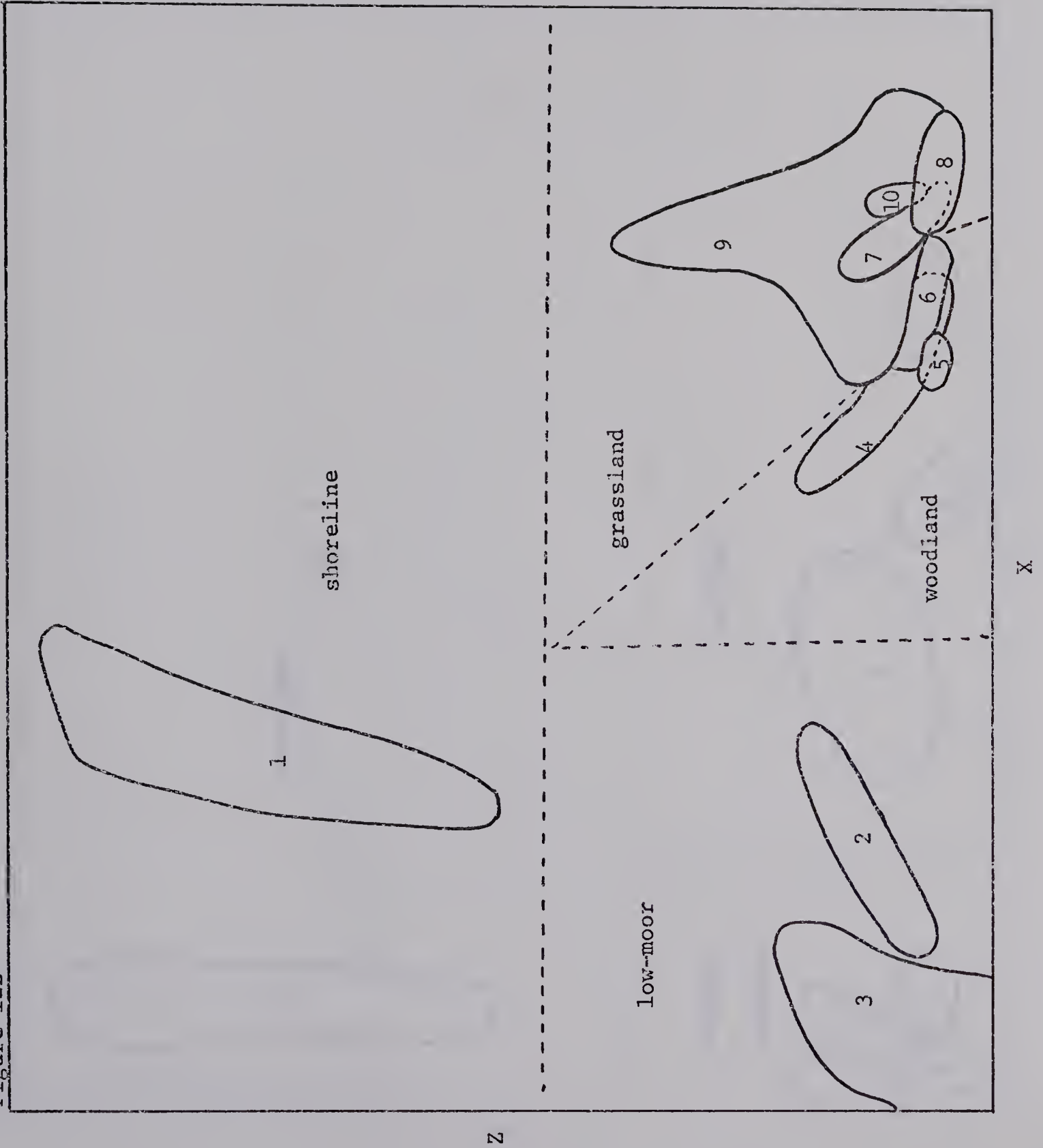


Figure 12C

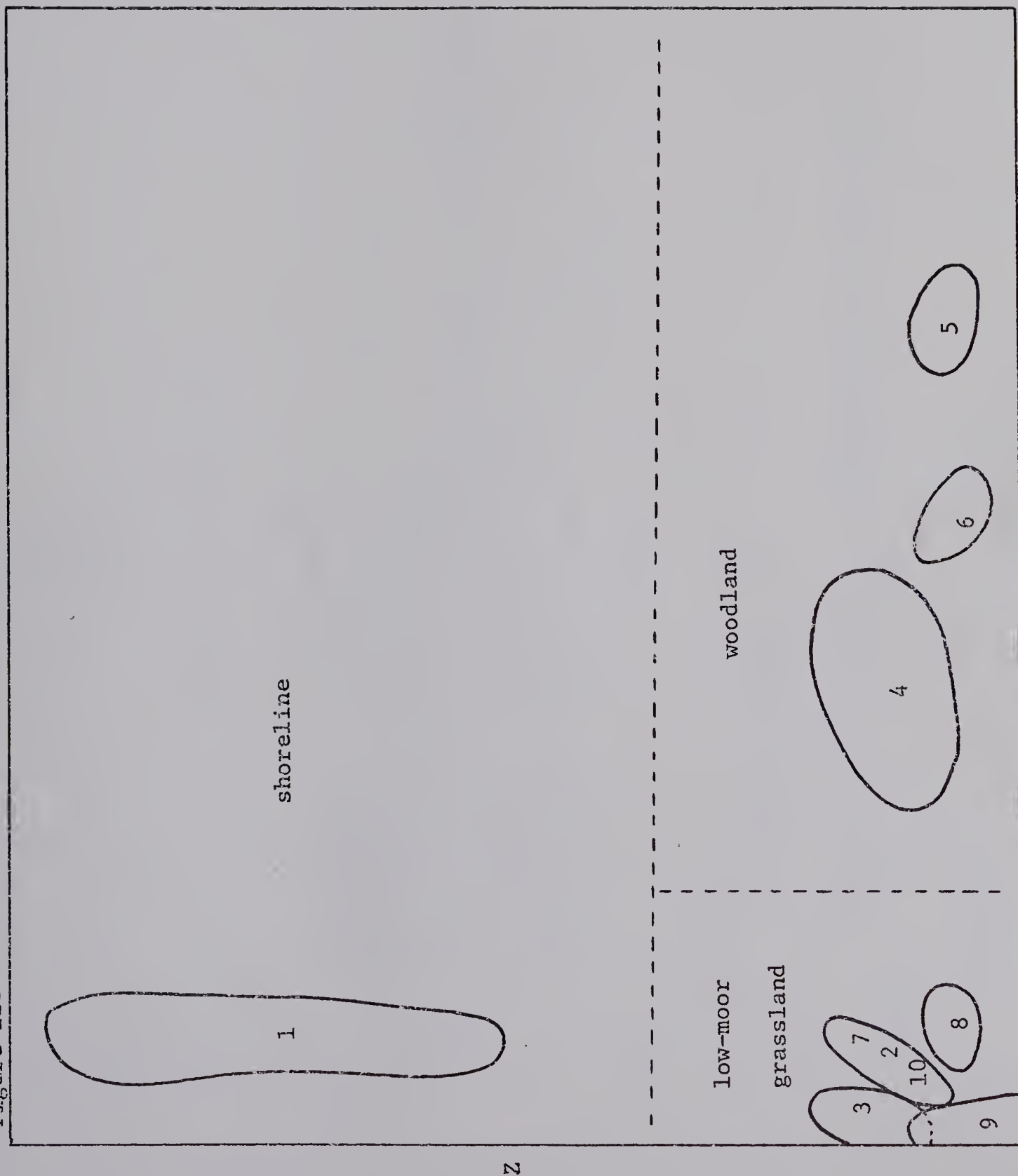


Figure 13. The three-dimensional orthogonal cluster ordination of the replicated clusters in the reconnaissance study unit.

- A. on the XY plane.
- B. on the XZ plane.
- C. on the YZ plane.

CODE	CLUSTER
1	<i>Scirpus validus</i> - <i>Cirsium arvense</i> - <i>Sonchus arvensis</i>
2	<i>Scotolochloa festuacea</i>
3	<i>Carex atherodes</i> - <i>Calamagrostis neglecta</i>
4	<i>Poa pratensis</i> - <i>Salix bebbiana</i> var. <i>perrostrata</i>
5	<i>Populus tremuloides</i> - <i>Poa pratensis</i> / <i>Salix bebbiana</i> var. <i>perrostrata</i>
6	<i>Populus tremuloides</i> - <i>Poa pratensis</i>
7	<i>Poa pratensis</i> - <i>Astragalus canadensis</i>
8	<i>Poa pratensis</i> - <i>Melilotus alba</i>
9	<i>Poa pratensis</i>
10	<i>Poa pratensis</i> - <i>Taraxacum</i> spp.

AXIS	EUCLIDEAN SPACE EXPLAINED
X	21%
Y	11%
Z	9%
Total	41%

Figure 13A

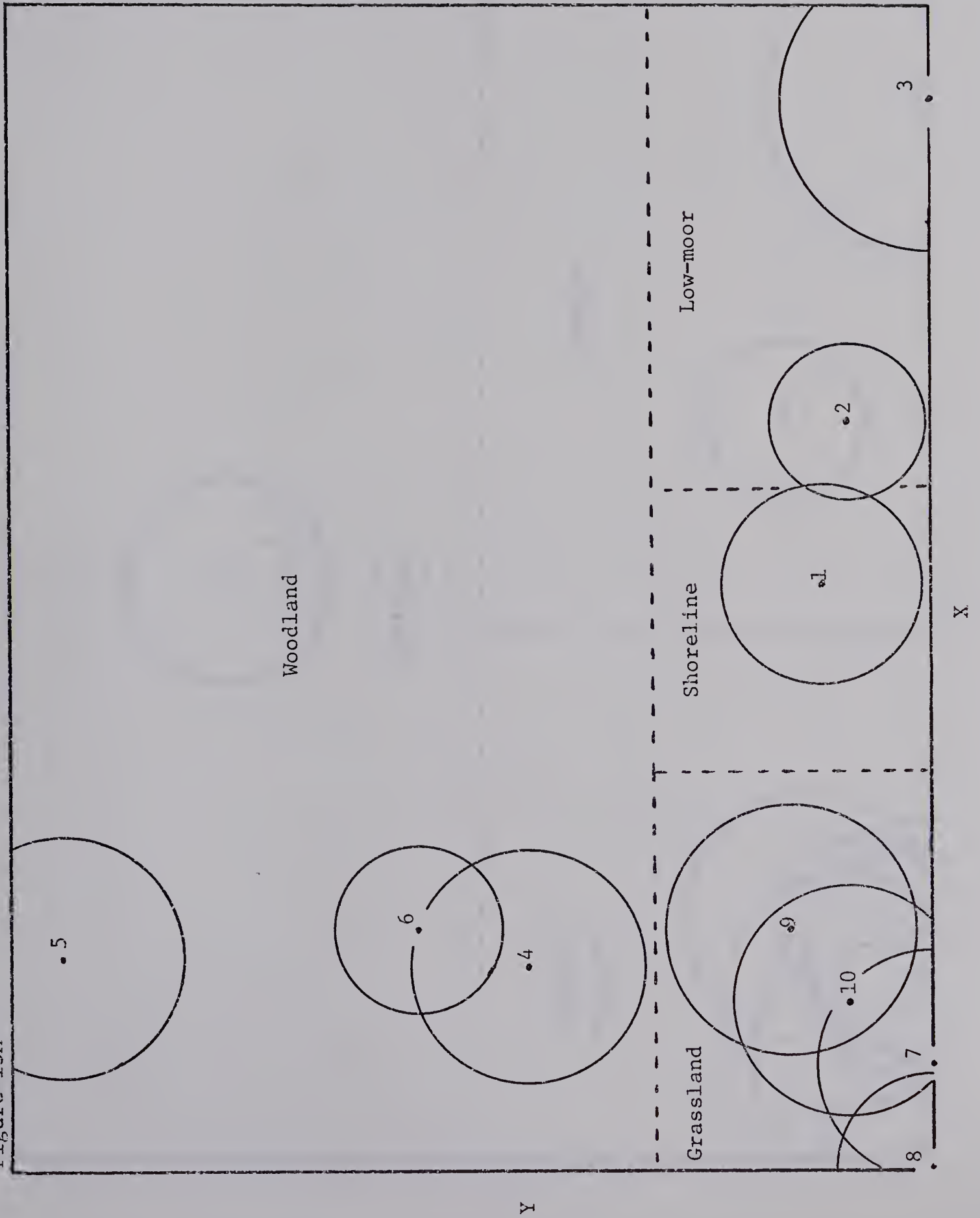


Figure 13B

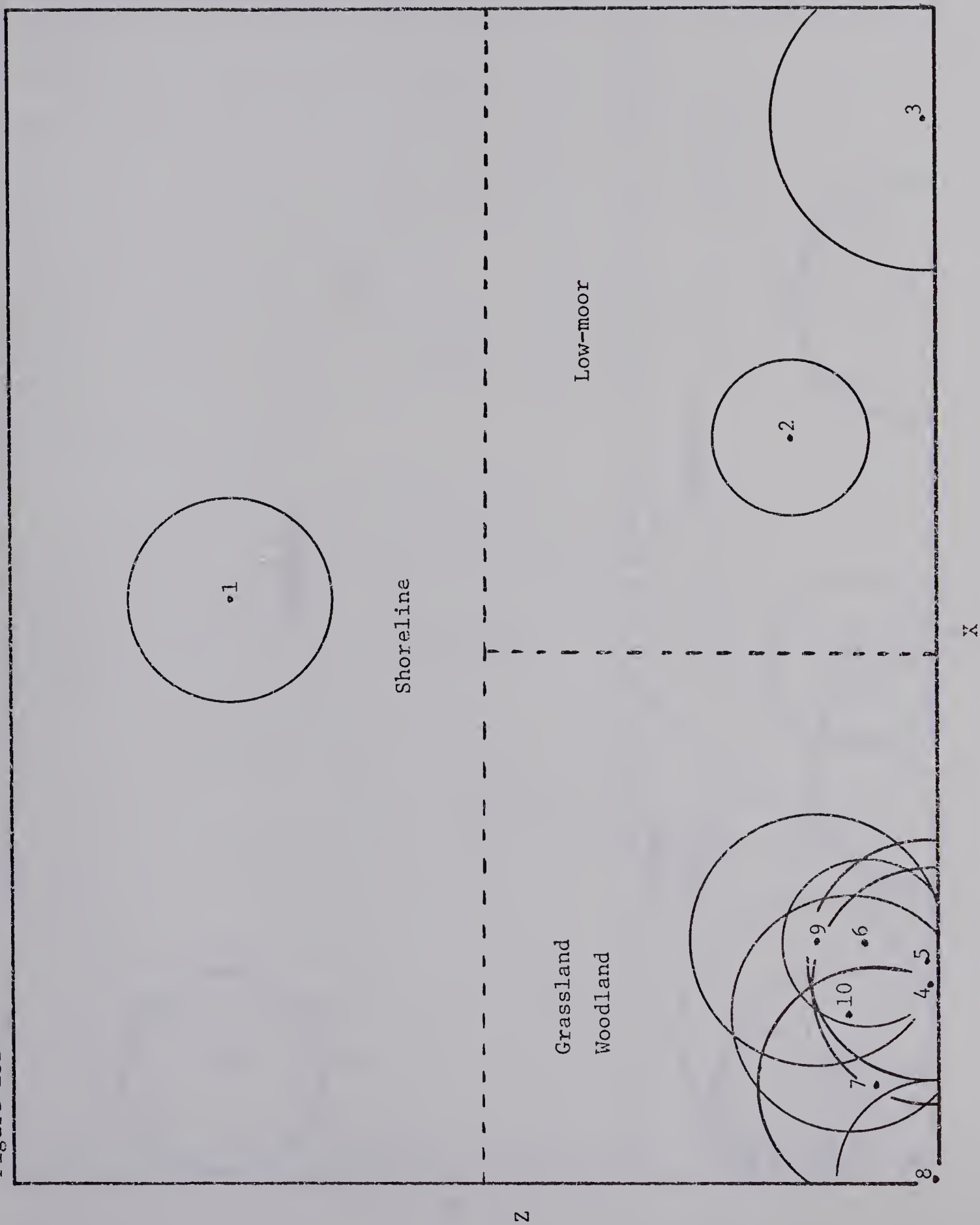
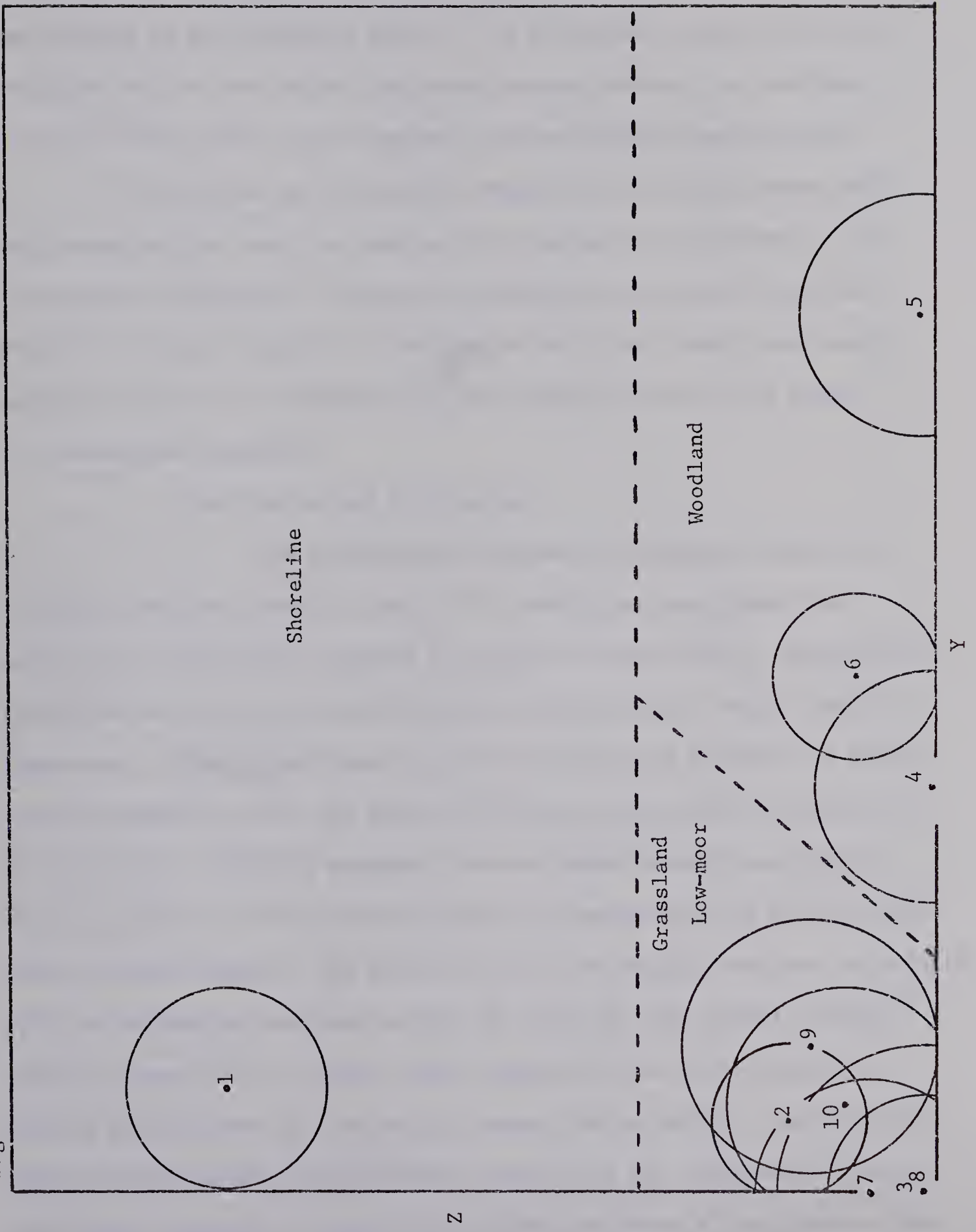


Figure 13C



but the size of the clusters was larger because the cluster sphere was defined by the periphery plots. The orthogonal cluster ordination explained 49% of the variability which existed within the intersite distance matrix while the orthogonal plot ordination explained 41%.

An analysis of the species found in the reconnaissance study unit revealed that very few species were dominants as defined by the four species statistics; frequency, presence cover, mean cover, and prominence index (Table 13). The species with the larger mean covers appeared to be most influential in the classification of the plots.

B. Statistical Analysis

1. Correlation and regression.

The correlations between the herbage production variables have been given in Table 14. Since grass and grass-like weight plus forb weight equalled the annual herbage weight, significant correlations naturally occurred between annual herbage weight and its components. Other significant correlations occurred between the annual herbage weight for 1970 and 1971 and the grass and grass-like weight for 1970 and 1971. The 1970 standing crop was significantly correlated with the 1970 and 1971 grass and grass-like weight and the 1970 and 1971 annual herbage weight. The 1970 and 1971 forb weights were not correlated with any production variable except the 1970 and 1971 annual herbage weight, respectively. Simple linear regression was also applied to various combinations of the herbage production variables. Excluding the relationships between annual herbage weight and its components, only one significant regression equation was determined where r^2 was greater than 50%. The regression equation was $Y = 7.02 + 0.57X$ where $Y = 1971$ grass

Table 13. Statistics defining the dominant species in the reconnaissance study unit.

Species	Frequency Percent ¹	Presence Cover ¹	Mean Cover ¹	Prominence Index ¹
<i>Poa pratensis</i> ²	58.6	80.4	47.1	359.0
<i>Calamagrostis neglecta</i> ³	40.0	49.6	19.8	124.7
<i>Carex atherodes</i> ⁴	28.6	50.4	14.4	76.3
<i>Populus tremuloides</i>	21.4	45.0	9.6	44.2
<i>Cirsium arvense</i>	38.6	23.1	8.9	55.2
<i>Melilotus alba</i>	51.4	17.3	8.9	63.2
<i>Taraxacum</i> spp.	60.0	14.0	8.7	67.0
<i>Salix bebbiana</i> var. <i>perrostrata</i>	24.3	34.5	8.4	41.2
<i>Astragalus agrestis</i> ⁵	40.0	20.9	8.3	52.3
<i>Juncus balticus</i>	30.0	21.7	6.5	35.8
<i>Sonchus arvensis</i>	32.9	19.0	6.3	35.9
<i>Astragalus canadensis</i>	22.9	26.0	5.9	28.3
<i>Fragaria virginiana</i> var. <i>glauca</i>	42.9	13.2	5.7	37.6
<i>Epilobium angustifolium</i>	21.4	24.5	5.2	23.4
<i>Achillea millefolium</i>	48.6	10.0	4.9	34.3
<i>Scirpus validus</i>	10.0	48.6	4.9	15.5
<i>Scolochloa festucacea</i>	10.0	43.9	4.4	14.1
<i>Solidago</i> spp.	12.9	28.0	3.6	13.0
<i>Aster pansus</i>	34.3	10.0	3.4	19.7
<i>Lactuca pulchella</i>	42.9	7.4	3.2	20.8
<i>Salix petiolaris</i>	12.9	22.8	2.9	10.4
<i>Populus balsamifera</i>	20.0	10.6	2.1	9.4
<i>Mentha arvensis</i> var. <i>villosa</i>	20.0	9.0	1.8	8.1

¹Refer to terminology on page 29.

²Predominantly *Poa pratensis* with some *P. compressa* and *P. glaucifolia*.

³Predominantly *Calamagrostis neglecta* with some *C. inexpansa*.

⁴Predominantly *Carex atherodes* with some *C. rostrata*.

⁵Predominantly *Astragalus agrestis* with some *A. flexuosus*.

Table 14. Correlation coefficients (r) matrix for the herbage production variables in the reconnaissance study unit.

Variable	1970			1971		
	Grass & Grass-like Weight	Forb Weight	Annual Herbage Weight	Grass & Grass-like Weight	Forb Weight	Forb Weight
1970 Forb Weight	-.11	1.00				
1970 Annual Herbage Weight	0.82**	0.47**	1.00			
1970 Standing Crop	0.50**	0.22	0.57**	1.00		
1971 Grass & Grass-like Weight	0.76**	-.11	0.61**	1.00		
1971 Forb Weight	-.03	0.24	0.11	0.15	1.00	
1971 Annual Herbage Weight	0.40**	0.16	0.45**	0.43**	0.40**	0.83**

**P < 0.01

and grass-like weight, $X = 1970$ grass and grass-like weight ($t=8.6$, $P < 0.01$) and $r^2 = 0.58$. A significant equation was also found for the 1970 to 1971 annual herbage weight; however, the regression equation accounted for less than 50% of the total sum of squares ($r^2=0.20$) in the analysis. The equation was $Y = 14.6 + 0.53X$ where $Y = 1971$ annual herbage weight and $X = 1970$ annual herbage weight ($t=3.7$, $P < 0.01$).

2. One-way analysis of variance.

Herbage production variables were collected for 10 of the clusters during the first week of August in 1970 and 1971. The analysis presented in Table 15 revealed that significant differences existed for most variables among the clusters defined from canopy coverage data. Significant differences among clusters did not exist for the 1971 annual herbage weight because the apparent differences among clusters were masked by intra-cluster variance and small sample sizes. The forb weight generally increased from the mesic to the xeric clusters. In contrast, the grass and grass-like weight was similar between the low-moor and grassland clusters but was reduced in the woodland clusters. The annual herbage weight grand means, 2480 kg/ha D.M. in 1970 and 2580 kg/ha D.M. in 1971, were not statistically different. The grass and grass-like weight grand mean decreased (not significantly) from 2000 kg/ha D.M. in 1970 to 1790 kg/ha D.M. in 1971 while the forb weight grand mean increased (not significantly) from 190 kg/ha D.M. in 1970 to 250 kg/ha D.M. in 1971. The standing crop grand mean indicated that litter accounted for 62% of the 6540 kg/ha D.M. available forage in the study unit (Table 15).

The annual herbage weights of the low-moor and grassland associations were not significantly different but the woodland association

Table 15. A one-way analysis of variance of each herbage production variable for¹ the replicated clusters in the reconnaissance study unit (kg/ha D.M.).

Cluster	No. of Plots	1970				1971		
		Grass & Weight	Forb Weight	Annual Herbage Weight	Standing Crop Weight	Grass-like Weight	Forb Weight	Annual Herbage Weight
<i>Scolochloa festuacea</i>	3	2350 ^{ab} ²	0 ^c	2360 ^{ab}	8430 ^a	3700 ^a	0 ^d	3500 ^a
<i>Carex atherodes</i> -								
<i>Calamagrostis neglecta</i>	12	3060 ^a	10 ^c	3090 ^{ab}	7130 ^{ab}	2470 ^{ab}	20 ^{cd}	2560 ^a
<i>Poa pratensis</i> - <i>Salix bebbiana</i> var. <i>perrostrata</i>	5	1000 ^{bc}	160 ^{bc}	1240 ^{bc}	3580 ^c	1290 ^{bc}	320 ^{abcd}	1980 ^a
<i>Populus tremuloides</i> -								
<i>Poa pratensis</i> / <i>Salix bebbiana</i> var. <i>perrostrata</i>	2	480 ^c	120 ^{bc}	610 ^c	4060 ^{bc}	740 ^c	40 ^{cd}	790 ^a
<i>Populus tremuloides</i> -								
<i>Poa pratensis</i>	2	1450 ^{abc}	50 ^{bc}	1560 ^{bc}	6850 ^{abc}	910 ^{bc}	100 ^{bcd}	1010 ^a
<i>Poa pratensis</i> -								
<i>Astragalus canadensis</i>	5	2330 ^{ab}	2290 ^a	4950 ^a	8830 ^a	2340 ^{ab}	1070 ^{ab}	3820 ^a
<i>Poa pratensis</i> -								
<i>Melilotus alba</i>	2	2160 ^{ab}	3680 ^a	5830 ^a	7630 ^{ab}	1460 ^{abc}	1390 ^a	2990 ^a
<i>Poa pratensis</i>	17	1850 ^{ab}	300 ^b	2300 ^{ab}	7060 ^{ab}	1470 ^{abc}	760 ^{ab}	2760 ^a
<i>Poa pratensis</i>								
<i>Taraxacum</i> spp.	2	1320 ^{abc}	280 ^b	1600 ^{bc}	4200 ^{bc}	1250 ^{bc}	550 ^{abc}	1820 ^a
Grand Mean	56	2010±200	190±310	2480±200	6540±150	1790±180	250±380	2500±190
F Value		3.23**	17.32***	3.90***	3.25**	3.20**	6.83***	1.94

¹Raw data has been transformed to the logarithmic scale and the means presented are geometric.²Numbers with the same superscript are not sig. different at P < 0.05 level (Duncan's New Multiple Range Test).

**p < 0.01

***p < 0.005

was significantly lower than the former associations (Table 16). It was found that the invasion of woody species reduced the mean annual herbage weight by 1570 kg/ha D.M. or 61%. The forb weight was found to be significantly different in the associations sampled. The highest forb weight was recorded for the grassland association while the woodland was the next highest (Table 16). The forb weight of the low-moor association was the lowest with a mean annual production of 15 kg/ha D.M. The grass and grass-like weight was consistent with the annual herbage weight. The one exception to this generalization occurred in 1971 when the grass and grass-like weight of the low-moor association was significantly different from the woodland and grassland associations (Table 16).

III. Island Study Unit

A. Plot Normalization

Ordinational classification following the method used in the reconnaissance and gradient study units was applied to the raw data matrix and 13 clusters were defined from 151 plots. One cluster was large and very heterogeneous being formed from plots found along the ecotone between the upland and lowland zones as shown in Figure 14. By analyzing the heterogeneous cluster as a separate unit, 12 sub-clusters were formed. Three of the sub-clusters were found to be similar to the clusters earlier defined and the similar clusters and sub-clusters were analyzed to determine if the relationship between weight and cover was consistent (Table 17). It was found that the total herbage cover was significantly lower for all sub-clusters even though the annual herbage weight was significantly lower in only the *Carex atherodes* sub-cluster.

Table 16. A one-way analysis of variance of each herbage production variable for the three sampled associations in the reconnaissance study unit (kg/ha D.M.).¹

Association	1970				1971		
	Grass & Grass-like Weight	Forb Weight	Annual Herbage Weight	Standing Crop Weight	Grass & Grass-like Weight	Forb Weight	Annual Herbage Weight
Low-moor	2940 ^{a2}	10 ^c	2980 ^a	7310 ^a	2610 ^a	20 ^c	2690 ^a
Woodland	930 ^b	125 ^b	1120 ^b	4255 ^b	1060 ^b	185 ^b	1400 ^b
Grassland	1910 ^a	570 ^a	2790 ^a	7125 ^a	1571 ^b	835 ^a	2860 ^a
F Value	10.93***	25.89***	7.63***	7.04***	9.71***	27.22***	4.48***

¹Raw data has been transformed to the logarithmic scale and the means are geometric.

²Numbers with the same superscript are not significantly different at P < 0.05 level (Duncan's New Multiple Range Test).

***P < 0.005

Figure 14. The upland-lowland ecotone.



Table 17. Comparison between the cluster and sub-cluster for each of three species following the initial analysis of the island study unit raw data matrix.¹

Item	Annual Herb. Wt. (kg/ha D.M.)	Percent of Cluster	Total Herbage Cover	Percent of Cluster
<i>Calamagrostis neglecta</i> cluster	3430 ^{a,2}		97.1 ^a	
<i>Calamagrostis neglecta</i> sub-cluster	2545 ^a	74	47.5 ^b	49
<i>Carex atherodes</i> cluster	4930 ^a		88.8 ^a	
<i>Carex atherodes</i> sub-cluster	2550 ^b	51	39.8 ^b	45
<i>Cirsium arvense</i> cluster	4210 ^a		92.7 ^a	
<i>Cirsium arvense</i> sub-cluster	3600 ^a	86	44.4 ^b	48

¹Raw data was transformed to the logarithmic scale and the means presented are geometric.

²Numbers with the same superscript are not significantly different at P < 0.05 level (Duncan's New Multiple Range Test).

The annual herbage weight was not significantly different between the clusters and sub-clusters for *Calamagrostis neglecta* or *Cirsium arvense*.

It was concluded that the coverage values had been underestimated for plots being assigned to the heterogeneous cluster and that plot normalization may partially correct this problem. Plot normalization would result in a loss of coverage information; however, a better classification may result from plots which have been normalized.

B. Ordinal Classification

The ordinal classification of the data matrix in the island study unit following plot normalization, resulted in the formation of 16 clusters into which 154 plots were distributed. The data matrix was of the order 185 plots by 70 species. Thirty-one plots were isolated during the analysis. The clusters formed as defined by the species having the largest mean canopy coverage (Table 18) were:

- (a) *Sonchus arvensis*,
- (b) *Urtica gracilis*,
- (c) *Cirsium arvense* - *Scirpus validus*,
- (d) *Calamagrostis neglecta* - *Cirsium arvense*,
- (e) *Calamagrostis neglecta* - *Carex atherodes*,
- (f) *Calamagrostis neglecta*,
- (g) *Calamagrostis neglecta* - *Scolochloa festuacea*,
- (h) *Scolochloa festuacea*,
- (i) *Mentha arvensis* var. *villosa*,
- (j) *Salix petiolaris*,
- (k) *Salix interior*,
- (l) *Salix bebbiana* var. *perrostrata* #1,

Table 18. The mean normalized coverage (%) of the cluster for the important species in the island study unit.

SPECIES	CLUSTERS	Lowland Zone										Upland Zone						
		Soar	Urgr	Ciar- Seva	Ciar	Cane- Caati	Cane	Cane- Scfe	Scfe	Meat	Sape	Sain	Sabe #1	Sabe #2	Poba	Potr	Popr- Potri	
CODE																		
<i>Urtica gracilis</i>	Urgr	10.0	100.0	15.5		P		5.3	5.3	1.6		P					P	
<i>Sonchus arvensis</i>	Soar	100.0		12.5		P		P	26.3	2.1		P		P	1.4	2.1	4.0	
<i>Scirpus validus</i>	Seva	2.5	25.0	40.4	3.3	2.9	P	10.1		5.8								
<i>Calamagrostis neglecta</i>	Cane	17.3	11.3	10.1	100.0	70.8	100.0	100.0		11.6	3.3	1.6	P		P	1.7		
<i>Cirsium arvense</i>	Ciar	41.9	34.3	74.1	81.7	5.3	P	P	26.3	15.0	1.1	7.5	P	P	P		2.7	
<i>Carex atherodes</i>	Caat	27.4	P	6.2	26.6	49.4	41.4	2.6	10.5	29.7	4.3	P	P	1.1	P	3.3	P	
<i>Scotolochloa festuacea</i>	Scfe	8.8		2.6		2.1	1.2	68.3	100.0	13.3								
<i>Mentha arvensis</i> var. <i>villosa</i>	Meat	5.8	P	2.6	14.6	4.7	2.2	6.2	5.3	100.0	1.2	6.3	P	P	P	P	P	
<i>Poa palustris</i>	Popa	P	2.5	1.1		P			23.7	P	2.9		3.0	2.3	P	1.7	P	
<i>Aster hesperius</i>	Ashe	3.1		P					26.3	1.7	P		P	P	P		1.5	
<i>Carex lasiocarpa</i>	Cala			1.2		P				1.5	P	P	P	P	P	3.3	2.0	
<i>Juncus balticus</i>	Juba	P		P		P				2.6	3.3	7.0	3.3	2.9	2.4		3.9	
<i>Salix petiolaris</i>	Sape						1.2				100.0			5.7			P	
<i>Salix interior</i>	Sain										1.1	100.0	P				1.7	
<i>Salix bebbiana</i> var. <i>perrostrata</i>	Sabe	P							P		15.8		100.0	100.0	10.6	42.7	10.1	
<i>Taraxacum</i> spp.	Tas.					P					P	1.4	P	P	1.6		1.4	
<i>Melilotus alba</i>	Meal										1.1		P		1.0	8.0	11.3	
<i>Fragaria virginiana</i> var. <i>glauca</i>	Frvi										P	P	P		1.2		1.9	
<i>Populus balsamifera</i>	Poba										P	20.3	5.1		100.0	25.2	6.2	
<i>Populus tremuloïdes</i>	Potr										1.8	1.4	19.8		P	100.0	43.9	
<i>Poa pratensis</i>	Popr			P	1.7						2.3	12.8	2.9	P	19.1	2.5	73.9	
<i>Trifolium repens</i>	Ttre									P							P	

Major clusters.

P - Mean normalized coverage was less than 1%.

- (m) *Salix bebbiana* var. *perrostrata* #2,
- (n) *Populus balsamifera*,
- (o) *Populus tremuloides*, and
- (p) *Poa pratensis* - *Populus tremuloides*.

Arranging these clusters approximately along the mesic to xeric gradient, two vegetational zones could be easily defined (Table 18). These were the lowland zone (moist) and the upland zone (drier).

Orthogonal cluster ordination presented in Figure 15 revealed that the clusters formed a continuum from the mesic to the xeric with the smaller clusters usually falling among the larger clusters. Five clusters representing the major species or species combinations which were most replicated have been presented in Figure 16. These major (most replicated) clusters were:

- (a) *Cirsium arvense* - *Scirpus validus*,
- (b) *Calamagrostis neglecta* - *Carex atherodes*,
- (c) *Salix petiolaris*,
- (d) *Salix bebbiana* var. *perrostrata* #1, and
- (e) *Poa pratensis* - *Populus tremuloides*.

A large discontinuity was evident between the three largest clusters, *Cirsium arvense* - *Scirpus validus*, *Calamagrostis neglecta* - *Carex atherodes* and *Poa pratensis* - *Populus tremuloides*. These clusters were analogous to the shoreline, low-moor and woodland associations, respectively of the reconnaissance and gradient study units. The three largest clusters illustrated the vegetative polarity which existed on the island. It was found that the X and Z axes of Figures 15 and 16 defined the greatest separation of these clusters.

Figure 15. The three-dimensional orthogonal cluster ordination of the replicated clusters in the island study unit.

		A. on the XY plane.	B. on the XZ plane.	C. on the YZ plane.
CODE	CLUSTER			
1	<i>Senecio arvensis</i>			
2	<i>Urtica gracilis</i>			
3	<i>Cirsium arvense - Scirpus validus</i>			
4	<i>Calamagrostis neglecta - Cirsium arvense</i>			
5	<i>Calamagrostis neglecta - Carex atherodes</i>			
6	<i>Calamagrostis neglecta</i>			
7	<i>Calamagrostis neglecta - Scolochloa festuacea</i>			
8	<i>Scolochloa festuacea</i>			
9	<i>Mentha arvensis var. villosa</i>			
10	<i>Salix petiolaris</i>			
11	<i>Salix interior</i>			
12	<i>Salix bebbiana var. perrostrata #1</i>			
13	<i>Salix bebbiana var. perrostrata #2</i>			
14	<i>Populus balsamifera</i>			
15	<i>Populus tremuloides</i>			
16	<i>Poa pratensis - Populus tremuloides</i>			
AXIS	EUCLIDEAN SPACE EXPLAINED			
X		22%		
Y		12%		
Z		<u>11%</u>		
Total				45%

Figure 15A

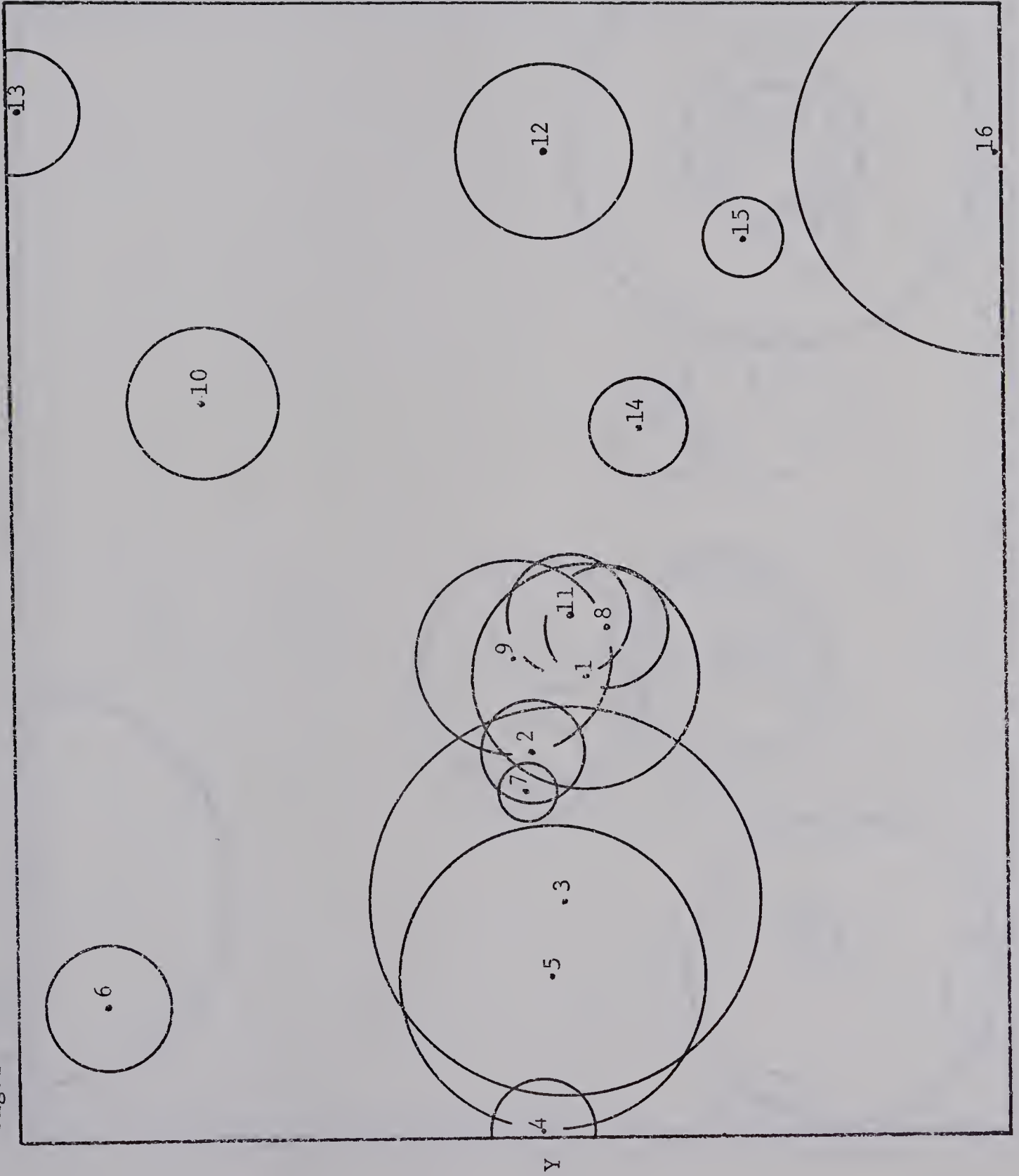


Figure 1.5E

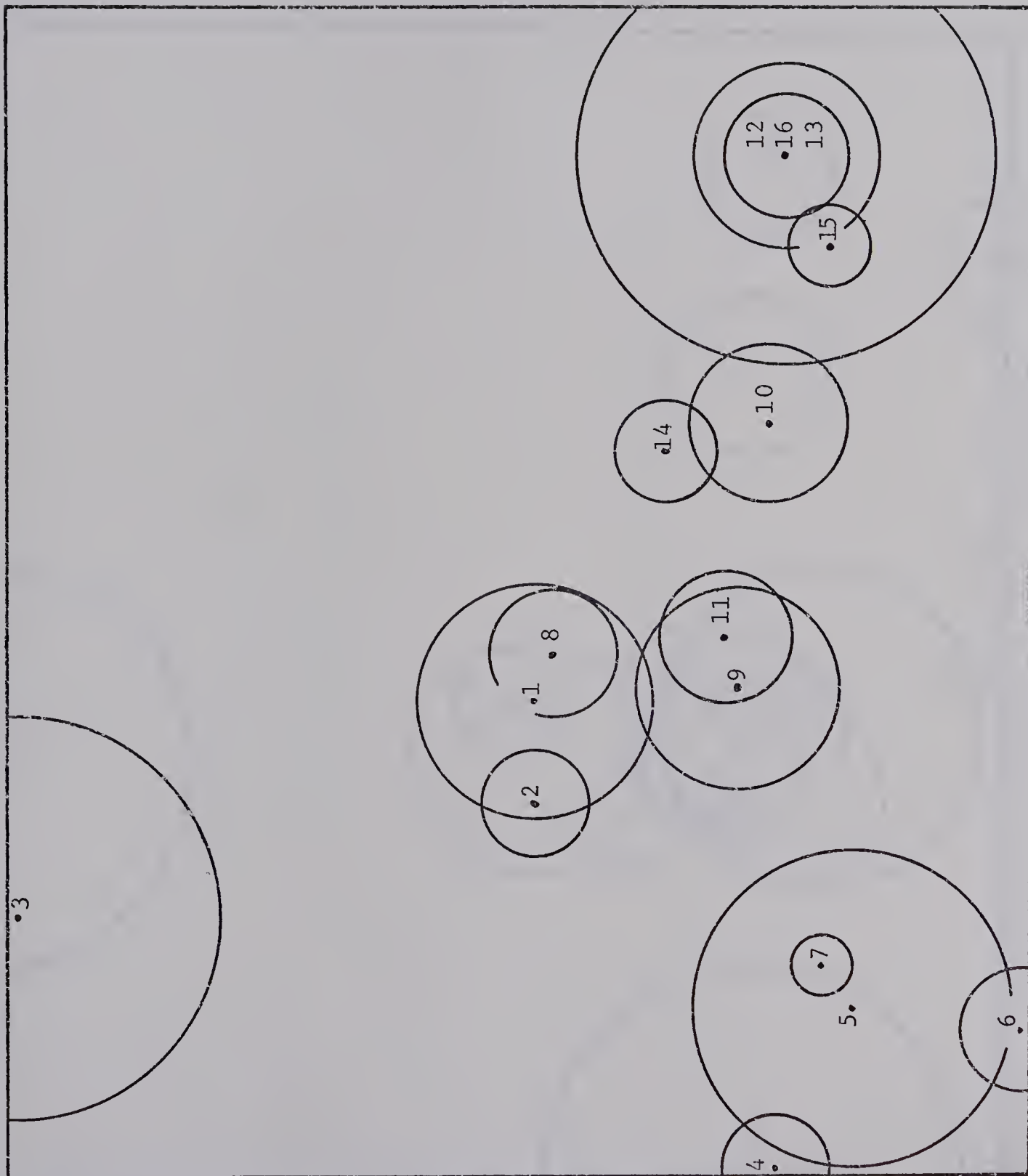


Figure 15C

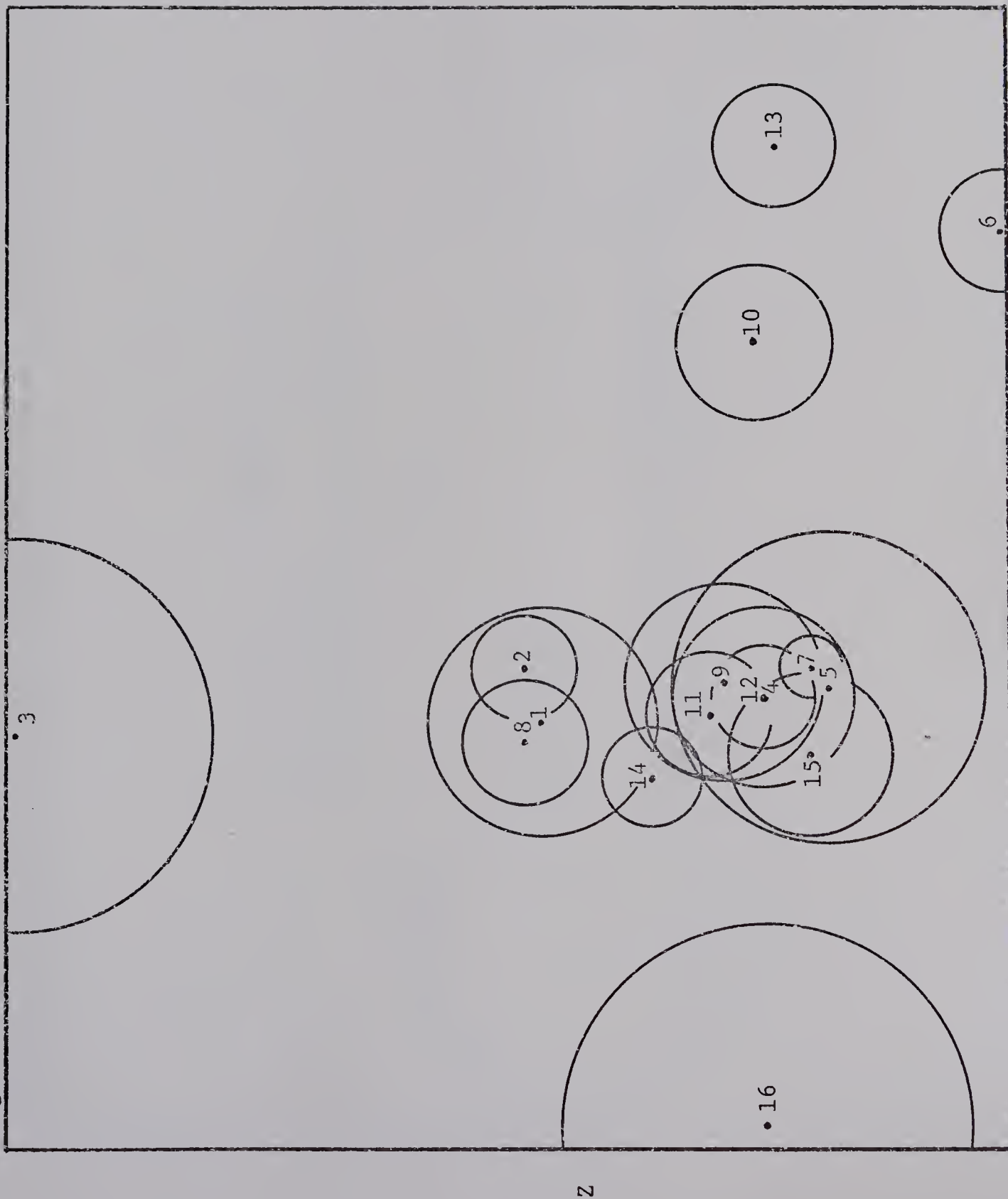


Figure 16. The three-dimensional orthogonal cluster ordination of the major clusters in the island study unit.

- A. on the XY plane.
- B. on the XZ plane.
- C. on the YZ plane.

CODE	CLUSTER
1	<i>Cirsium arvense</i> - <i>Scirpus validus</i>
2	<i>Calamagrostis neglecta</i> - <i>Carex atherodes</i>
3	<i>Salix petiolaris</i>
4	<i>Salix bebbiana</i> var. <i>perrostrata</i> #1
5	<i>Poa pratensis</i> - <i>Populus tremuloides</i>

Figure 16A

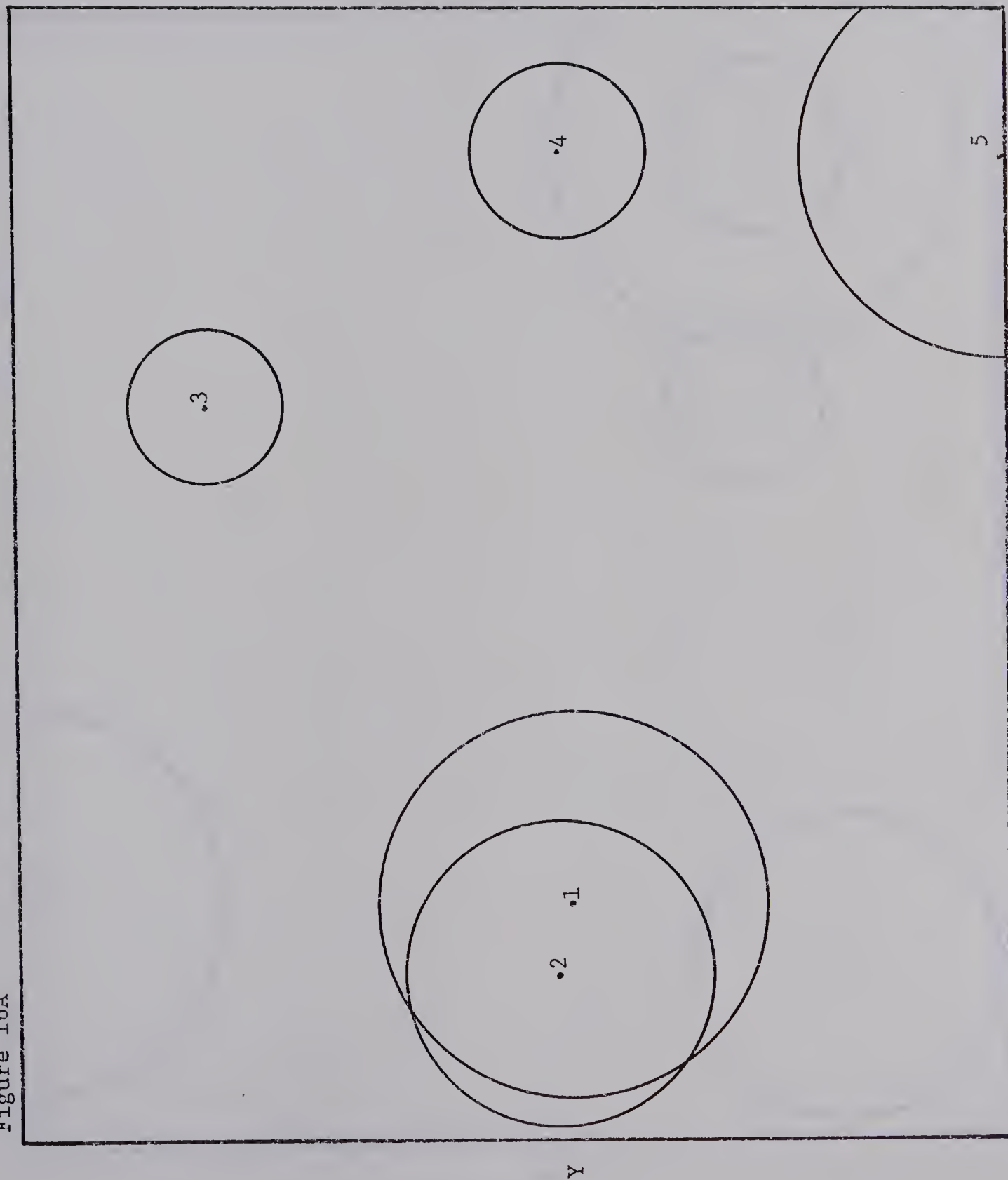
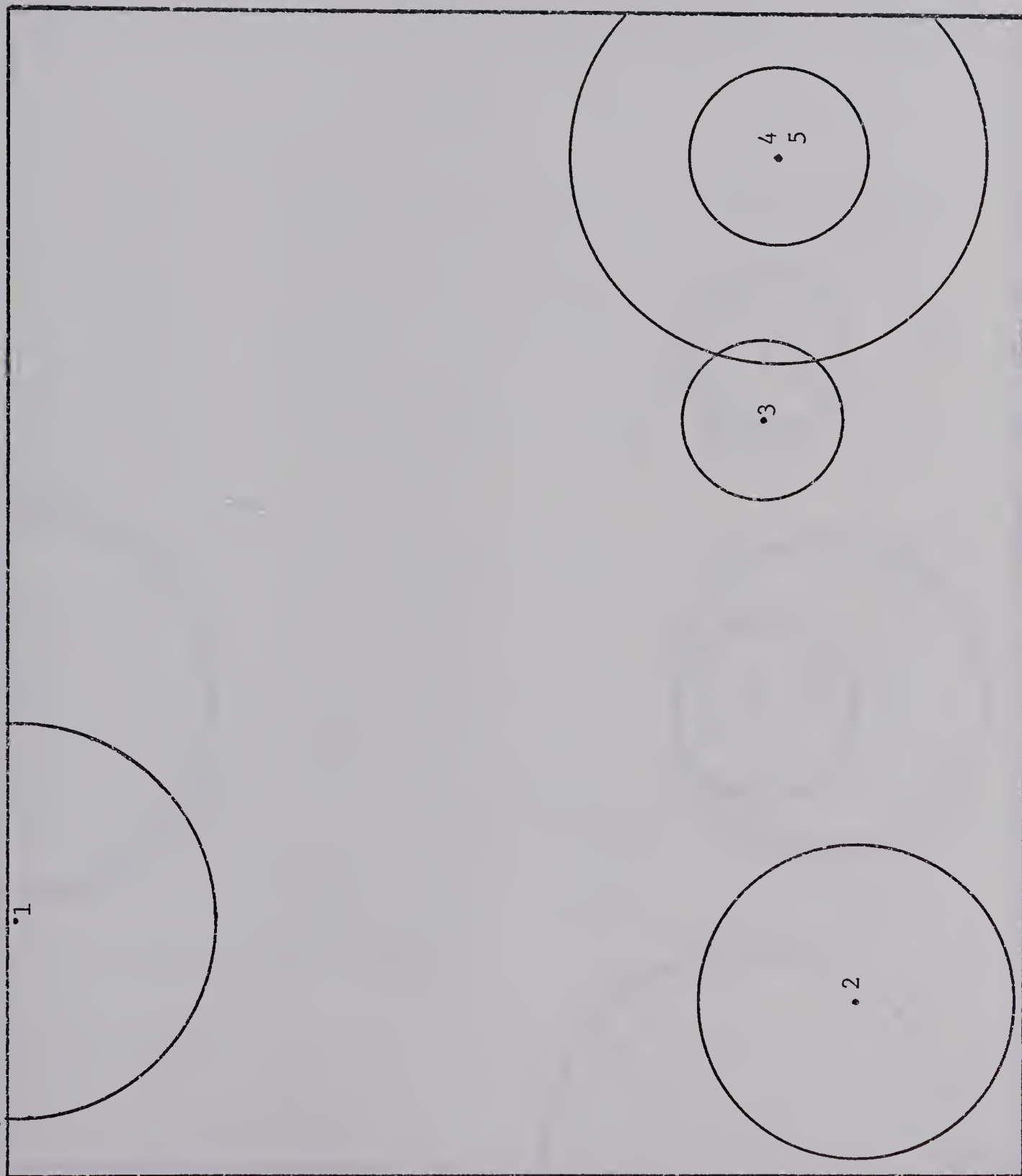


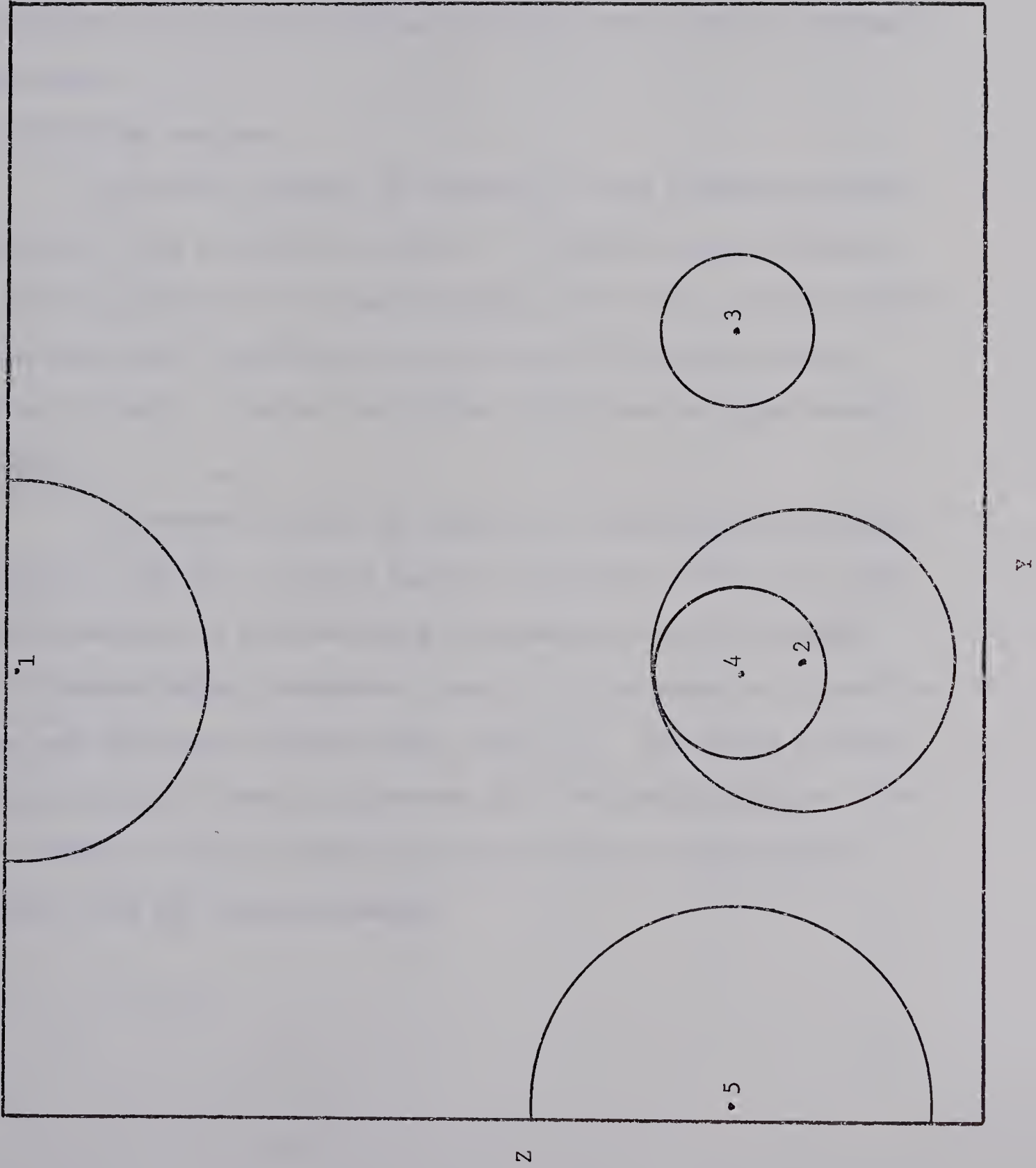
Figure 16B



z

x

Figure 16C



The analysis of the species found in the island study unit revealed that very few species were dominants as defined by the four species statistics (Table 19). *Calamagrostis neglecta*, *Carex atherodes* and *Cirsium arvense* had the highest frequency, mean cover and prominence index values.

C. Statistical Analysis

The one-way analysis of variance for each herbage production variable has been presented in Table 20. Differences among clusters were highly significant for these variables. The wooded clusters showed significantly less production than the low-moor clusters; however, the *Poa pratensis* - *Populus tremuloides* cluster was not significantly different.

The one-way analysis of variance for each herbage production variable for the major clusters has been presented in Table 21. Significant differences occurred for all variables except forb weight. The differences among clusters were similar for the grass and grass-like weight and the annual herbage weight (Table 21). The upland clusters were significantly lower in production than the lowland clusters. The *Poa pratensis* - *Populus tremuloides* cluster was not significantly different from the lowland clusters.

Table 19. Statistics defining the dominant species in the island study unit.¹

Species	Frequency Percent ¹	Presence Cover ¹	Mean Cover ¹	Prominence Index ¹
<i>Calamagrostis neglecta</i>	57.8	49.7	28.7	218.6
<i>Carex atherodes</i> ²	63.2	32.3	20.4	162.2
<i>Cirsium arvense</i>	65.4	27.8	18.2	147.0
<i>Poa pratensis</i> ³	36.2	40.0	14.5	87.2
<i>Salix bebbiana</i> var. <i>perrostrata</i>	28.1	48.6	13.7	72.4
<i>Populus tremuloides</i>	20.5	56.4	11.6	52.5
<i>Salix petiolaris</i>	18.9	59.6	11.3	49.0
<i>Scirpus validus</i>	36.8	21.5	7.9	47.9
<i>Sonchus arvensis</i>	49.7	13.9	6.9	48.9
<i>Mentha arvensis</i> var. <i>villosa</i>	48.6	14.1	6.8	47.8
<i>Populus balsamifera</i>	17.3	38.5	6.6	27.7
<i>Urtica gracilis</i>	30.8	16.6	5.1	28.4
<i>Juncus balticus</i>	34.6	12.9	4.4	26.2
<i>Scolochloa festucacea</i>	18.4	20.8	3.8	16.4
<i>Carex lasiocarpa</i>	16.8	16.8	2.8	11.5
<i>Poa palustris</i>	35.1	7.3	2.6	15.1
<i>Melilotus alba</i>	15.7	12.5	2.0	7.8
<i>Aster hesperius</i>	32.4	5.8	1.9	10.6
<i>Salix interior</i>	3.8	42.5	1.6	3.1
<i>Trifolium repens</i>	2.7	42.4	1.1	1.9
<i>Taraxacum</i> spp.	29.2	3.4	1.0	5.4
<i>Fragaria virginiana</i> var. <i>glauca</i>	17.8	3.9	0.7	2.9

¹Refer to terminology on page 29.

²Predominantly *Carex atherodes* with some *Carex rostrata*.

³Predominantly *Poa pratensis* with some *Poa compressa* and *Poa glaucifolia*.

Table 20. A one-way analysis of variance of each herbage production variable for the replicated clusters in the island study unit.¹

Cluster	No. of Plots	Grass & Grass-like Weight (kg/ha D.M.)	Forb Weight (kg/ha D.M.)	Annual Herbage Weight (kg/ha D.M.)	Species Richness (no./plot)
<i>Sonchus arvensis</i>	5	785 ^{cde} ²	1865 ^a	3165 ^{abc}	8.1 ^{ab}
<i>Urtica gracilis</i>	2	1015 ^{bcde}	2520 ^a	4155 ^{ab}	8.5 ^{ab}
<i>Cirsium arvense</i> - <i>Scirpus validus</i>	26	1755 ^{abc}	915 ^{ab}	3710 ^{abc}	6.9 ^{ab}
<i>Calamagrostis neglecta</i> - <i>Cirsium arvense</i>	2	1225 ^{abcd}	470 ^{ab}	1845 ^{abc}	5.5 ^b
<i>Calamagrostis neglecta</i> - <i>Carex atherodes</i>	49	3015 ^{ab}	145 ^{bc}	3345 ^{abc}	5.7 ^b
<i>Calamagrostis neglecta</i>	2	2230 ^{abc}	0 ^c	2235 ^{abc}	6.5 ^{ab}
<i>Calamagrostis neglecta</i> - <i>Scolochloa festuacea</i>	2	3725 ^a	195 ^{bc}	3930 ^{ab}	7.9 ^{ab}
<i>Scolochloa festuacea</i>	2	2090 ^{abc}	2220 ^a	4345 ^a	8.5 ^{ab}
<i>Mentha arvensis</i> var. <i>villosa</i>	4	2020 ^{abc}	850 ^{ab}	3005 ^{abc}	8.9 ^{ab}
<i>Salix petiolaris</i>	16	420 ^{def}	30 ^{bc}	525 ^{de}	8.8 ^{ab}
<i>Salix interior</i>	2	730 ^{cde}	690 ^{ab}	1440 ^{bcd}	10.8 ^a
<i>Salix bebbiana</i> var. <i>perrostrata</i> #1	9	415 ^{def}	80 ^{bc}	535 ^{de}	10.4 ^a
<i>Salix bebbiana</i> var. <i>perrostrata</i> #2	3	305 ^{ef}	15 ^{bc}	315 ^e	8.3 ^{ab}
<i>Populus balsamifera</i>	5	440 ^{def}	85 ^{bc}	550 ^{de}	10.4 ^a
<i>Populus tremuloides</i>	2	175 ^f	205 ^{bc}	440 ^e	10.5 ^a
<i>Poa pratensis</i> - <i>Populus tremuloides</i>	23	815 ^{cde}	365 ^{ab}	1280 ^{cde}	10.4 ^a
Grand Mean	154	1300±185	265±200	1800±130	7.6±1.4
F Value		13.17***	6.28***	17.27***	5.78***

¹Raw data was transformed to the logarithmic scale and the means presented are geometric.

²Numbers with the same superscript are not significantly different at P < 0.05 level (Duncan's New Multiple Range Test).

***p < 0.005

Table 21. A one-way analysis of variance of each herbage production variable¹ for the major clusters in the island study unit.

Cluster	Association ²	No. of Plots	Grass & Weight (kg/ha D.M.)	Forb Weight (kg/ha D.M.)	Annual Herbage Weight (kg/ha D.M.)	Species Richness (no./plot)
<i>Cirsium arvense</i> - <i>Scirpus validus</i>	Shoreline	26	1755 ^{ab3}	915 ^a	3710 ^a	6.9 ^{ab}
<i>Calamagrostis neglecta</i> - <i>Carex atherodes</i>	Low-moor	49	3015 ^a	145 ^a	3345 ^{ab}	5.7 ^b
<i>Salix petiolaris</i>	Woodland	16	420 ^c	80 ^a	525 ^c	8.8 ^{ab}
<i>Salix bebbiana</i> var. <i>perrostrata</i> #1	Woodland	9	415 ^c	80 ^a	535 ^c	10.4 ^a
<i>Poa pratensis</i> - <i>Populus tremuloides</i>	Woodland	23	815 ^{bc}	365 ^a	1280 ^{bc}	10.4 ^a

¹Raw data was transformed to the logarithmic scale and the means presented are geometric.

²The association in which the cluster was found.

³Numbers with the same superscript are not significantly different at $P < 0.05$ (Duncan's New Multiple Range Test).

DISCUSSION

1. Species

A. The Degree of Dominance of a Species

The definition of the clusters appeared to be closely related to the independent species found in the study unit. The degree of classification was related to the number of independent species entering into the distance equation. The more species entered, the finer was the resulting classification (sensu Williams and Lambert, 1959). To measure the individual species contribution to ordination classification, inverse ordination classification was conducted for the gradient study unit to determine which species were acting independently or individualistically (sensu Gleason, 1926). It was found that those species with the largest presence cover, mean cover or prominence index usually acted independently. The exception was *Mentha arvensis* var. *villosa* which was grouped with the non-independent species. The index of dissimilarity of the independent species was highly correlated with the presence cover, mean cover and prominence index of the same species (Table 3). Mean cover was the statistic which correlated the most closely with the index of dissimilarity ($r=0.93$) and has been used in the present study as the measure of the degree of dominance of a species in the study unit. The degree of dominance was a measure of the influence of an independent species in ordination classification.

The species having large mean cover values appeared to be most influential in the determination of intersite distances because they contributed the most to the distance measurement between sites. This has been clearly expressed by *Poa pratensis* and *Calamagrostis neglecta*

in the gradient study unit (Table 1). The ecological amplitude of *Poa pratensis* corresponded with the zone of vegetation at the higher elevations (upland zone) while the ecological amplitude of *Calamagrostis neglecta* corresponded to the zone of vegetation at the lower elevations (lowland zone) (Figures 9, 10, 11). The intersite distance between a site in the lowland zone and one in the upland zone would be large because of the great differences in the quantitative value of each species, i.e., the "presence-absence" of *Poa pratensis* and *Calamagrostis neglecta*. Sites within either zone would have a small intersite distance because the quantitative species values would be similar. However, the inclusion of all independent species refined the classification producing the "best" set of clusters inherent in the data (Carmichael, 1970).

Ordination of the independent species presented the dissimilarity relationships between these species (Figure 8) which were not evident from the dissimilarity index (Table 2). The largest dissimilarity (interspecies distance) was recorded between *Poa pratensis* and *Calamagrostis neglecta* (Figure 8). This dissimilarity was suggested by the ecological amplitudes of *Poa pratensis* and *Calamagrostis neglecta* (Figures 10, 11). The remaining independent species were found to be intermediate between *Poa pratensis* and *Calamagrostis neglecta*. The distribution of the independent species in the ordination field was similar to the cluster distribution along the X-axis (Figures 6, 7). This relationship indicated that these independent species were influential in the orthogonal classification of the plots.

B. Relic Species

The recently declining water levels of Beaverhill Lake had

caused a rapid succession in the vegetation on the island. This unstabilized state of the vegetation caused a problem during vegetational sampling because species which were common to the lowland zone were present as relics in the upland zone (Table 18). Due to these relic species, stands of vegetation were not easily defined and were difficult to delineate. In the present study, it was found that a representative sample of the vegetation was obtained by employing a restricted random method of plot location. This method appeared to effectively eliminate observer errors during the location of the plot and resulted in an equal chance of all vegetation in the study unit being sampled.

Cirsium arvense and *Sonchus arvensis* were the only relic species which caused distortion in cluster ordination. These species recorded the highest canopy coverage in the shoreline association; however, they were very common in the upland zone as relics (Table 18). This occurrence caused the clusters of the shoreline association to be placed closer, in ordination, to the clusters of the upland zone than would be expected (Figures 7, 13, 15). This distortion caused the clusters of the low-moor association to be more mesic on the X-axis than the shoreline association which had a higher soil moisture value (Table 11).

II. Island Vegetation

The major assumptions made in the present study were:

(a) The species composition of a cluster was a reliable criterion for determining its relative proximity to other clusters in Euclidean space.

(b) Species with similar ecological requirements occurred in

clusters of the same association.

(c) The few environmental factors affecting the distribution of the clusters could be represented by axes defining the orthogonal ordination (*sensu* Swan et al., 1969).

The orthogonal cluster ordinations presented in Figures 7, 13, and 15 for the gradient, reconnaissance and island study units, respectively, all revealed continuities and discontinuities in the vegetational structure of the island and satisfied the mentioned assumptions. In general, the X-axis separated the lowland clusters from the upland clusters and defined the upland and lowland zones. It would appear that the distribution of the species on the island was mainly associated with elevation of the site above the lake level; the level of soil moisture was closely associated, since the cluster position on the X-axis was highly correlated with elevation ($r=-.83$) and soil moisture ($r=0.81$) means for each cluster. The elevation and soil moisture means for each cluster were highly correlated ($r=-.83$, Table 5). The elevation and soil moisture data from each plot were not correlated ($r=-.17$, Table 4) even though a relationship appeared to exist in Figure 9. Since soil moisture was determined only during June, its true relationship with elevation may not have been expressed in the individual plots. In the present study, soil moisture would have been measured three times had it not been for heavy June rains which rendered further determination meaningless. The effect of the June rains was clearly illustrated by the drop of 0.5°C in the July grand mean for soil temperature compared with the June grand mean (Table 8).

The Y-axis was always associated with a subdivision within the upland zone. This was readily apparent in the reconnaissance study unit

(Figure 13) but the separation in the gradient study unit was more dramatic (Figure 7). The *Salix* dominated clusters were separated from both the *Populus* and *Poa* dominated clusters (Figure 7). For the purposes of this study, the *Salix* and the *Populus* dominated clusters have been placed in the woodland association while the remainder of the upland clusters formed the grassland association. The grassland association was not definable in the island study unit because the *Poa* dominated plots were included in the *Poa pratensis* - *Populus tremuloides* cluster. The Y-axis in the island study unit removed the *Salix* dominated clusters from the *Populus* dominated clusters. The regression analysis of the Y-axis in the gradient study unit revealed that soil temperature at 15 cm and the amount of available phosphorous were highly associated ($R^2=0.88$). June temperature was the most significant variable (Table 6).

The Z-axis separated the lowland zone into the shoreline and low-moor associations (Figures 13, 16) except in the gradient study unit where the shoreline association was represented by the *Cirsium arvense* cluster (Figure 7). The *Cirsium arvense* cluster appeared to be a relic of an old shoreline; it was in transition to the low-moor association as revealed by the high occurrence of low-moor and grassland species (Appendix 1). The regression of environmental and edaphic variables upon the Z-axis revealed that the amount of available phosphorous and soil pH were closely associated ($R^2=0.71$); however, only the phosphorous regression coefficient was significant.

A. The Lowland Zone

The lowland zone occurred on the low elevation, high moisture section of the island. The gradient study unit revealed that the lowland

zone had significantly higher soil moisture and sodium levels and significantly lower elevation and phosphorous levels than the upland zone. Subdividing the lowland zone resulted in the shoreline and low-moor associations being defined by the Z-axis.

1. The shoreline association.

The shoreline association formed the outer periphery of the island. It can be observed as the dark outer band in Figure 1. The shoreline association occupied the most mesic regions of the island and was generally dominated by the moisture tolerant species *Cirsium arvense* and *Scirpus validus*. *Urtica gracilis* and *Sonchus arvensis* were also very prominent. *Scirpus validus* was dominant on the mesic sites of the association and was analogous to the reed-swamp association of Lewis et al. (1928). *Cirsium arvense*, *Urtica gracilis* and *Sonchus arvensis* were found in the drier sites of the association. These species were not found in the reed-swamp association of Lewis et al. (1928). The *Cirsium arvense* cluster of the gradient study unit revealed that this association may contain low quantities of available phosphorous (Table 10) and an abundance of moisture (Table 9).

2. The low-moor association.

The low-moor association may be observed in Figure 1 as the light colored vegetation immediately inside the shoreline association. The dominant species forming clusters in the low-moor association were *Calamagrostis neglecta*, *Carex atherodes* and *Scolochloa festuacea*. The largest area of this association was dominated by *Calamagrostis neglecta*. Lewis et al. (1928) and Moss (1955) place *Carex atherodes* and *Scolochloa festuacea* in the reed-swamp association; however, in the present study these species were closely associated with *Calamagrostis*

neglecta (Appendices 1, 3, Table 18). *Scolochloa festucacea* and *Carex atherodes* appeared to favor the moist sites of the low-moor association. Other prominent species in this association were *Mentha arvensis* var. *villosa*, *Cirsium arvense*, *Scirpus validus* and *Calamagrostis inexpansa*. An example of the low-moor association has been presented in Figure 17 where relic stands of the shoreline association may be observed among stands of the low-moor association.

Wroe (1971) found that the *Carex atherodes* community occupied the depressions which held water during part of the growing season. He noted that *Carex atherodes* favored the shallow water while *Scirpus* spp. favored deeper water.

B. The Upland Zone

The upland zone occupied the inner section of the island which had the higher elevation and was approximately defined by the mesic extremity of the *Salix* spp. (Figures 1, 14). In the present study, this zone has been arbitrarily divided into two association, namely the woodland and grassland associations. The division was made in this fashion to test the reduction in herbage production resulting from the invasion of woody species. Orthogonal cluster ordination of the reconnaissance study unit (Figure 13) complimented this division of the upland zone. However, the orthogonal cluster ordination of the gradient study unit (Figure 7) and the island study unit (Figure 15) separated the *Salix* and the *Populus* dominated clusters.

1. The woodland association.

The dominant species of the woodland association were *Populus tremuloides*, *Salix bebbiana* var. *perrostrata* and *Salix petiolaris*

Figure 17. The low-moor association.



while *Poa pratensis*, *Melilotus alba* and *Populus balsamifera* were prominent. An example of the *Salix* dominated clusters has been given in Figure 18 while an example of the *Populus* dominated clusters has been presented in Figure 19. The canopies of the woodland clusters ranged from a relatively open canopy as shown in Figure 18 to a very closed and dense canopy as shown in Figure 19. Where the canopy was relatively open as shown in the right section of Figure 1, the herbaceous stratum was well developed and was primarily dominated by *Poa pratensis* and *Melilotus alba*. *Taraxacum* spp., *Fragaria virginiana* var. *glauca* and *Lactuca pulchella* were prominent forbs in the *Populus* dominated clusters while *Juncus balticus* was prominent in the *Salix* dominated clusters. When the canopy was closed as shown in the left section of Figure 1, the herbaceous stratum was very suppressed. *Juncus balticus* and *Melilotus alba* were prominent under the *Salix* canopy while *Poa pratensis* and *Taraxacum* spp. were dominant under the closed *Populus* canopy. The woodland association of the gradient study unit was found to be significantly lower than the other associations in the depth of the organic soil, soil pH and soil moisture and higher for shrub density and tree density (Tables 10, 11). Since the woodland association was composed of shrubs and trees, it would be expected to be significantly different from the other associations in shrub and tree densities.

2. The grassland association.

The grassland association occurred as openings between stands of the woodland association and was represented in only the intensively sampled study units; the gradient and reconnaissance study units. The largest grassland stand occurred in the center of the

Figure 18. A *Salix* dominated stand in the woodland association.



Figure 19. A *Populus* dominated stand in the woodland association.



island (Figure 1). *Poa pratensis* was the dominant grass and a variety of forbs were also present. *Melilotus alba* was the dominant forb while *Astragalus canadensis*, *Astragalus agrestis*, *Taraxacum* spp., *Lactuca puchella* and *Epilobium angustilifolium* were prominent. Clones of *Artemisia lucoviciana* var. *gnaphalodes*, *Thermopsis rhombilifolia*, *Cirsium arvense* and *Sonchus arvensis* were also found in the grassland association. The latter two species appeared to be relics of an old shoreline association. A relic stand of *Carex atherodes* was also found in the grassland association growing in the shade of a large rock.

The grassland association of the gradient study unit was significantly higher in June and July soil temperatures than the other associations (Table 11). Soil moisture in the grassland association was significantly higher than in the woodland association and significantly lower than the shoreline and low-moor associations (Table 11). Of the edaphic variables presented in Table 12, the only significant difference between the grassland association and all other associations was in its lower quantity of potassium. An example of the grassland association has been presented in Figure 20; the area illustrated was extensively sampled in the reconnaissance study unit.

III. Herbage Production

It was readily observable from Tables 10, 16 and 21 that the annual herbage weight of the shoreline, low-moor and grassland associations were not significantly different. In general, the shoreline association was the highest producer of forbs while the low-moor association produced the highest grass and grass-like weight. The invasion of woody species caused a marked reduction in annual herbage weight (Tables 10, 16, 21)

Figure 20. The grassland association.



but little change in the environmental and edaphic variables was observed (Tables 11, 12). Therefore the sites occupied by the woodland association have been assumed to not differ from the sites of the other associations in potential herbage production. Averaging all the annual herbage weight means given in Tables 10, 16 and 21 for the shoreline, low-moor and grassland associations, it was found that the mean annual herbage weight was approximately 2820 kg/ha D.M. while the mean annual herbage weight for the woodland association was approximately 905 kg/ha D.M. The reduction of annual herbage weight associated with the invasion of woody species was approximately 1915 kg/ha D.M. or 68%.

The standing crop was also reduced by the invasion of woody species (Table 16). The reduction observed was 2765 kg/ha D.M. or 37%. Litter accounted for 4000 kg/ha D.M. or 62% of the potentially available forage of 6540 kg/ha D.M. found in the reconnaissance study unit (Table 15).

Wroe (1971) found that communities in Central Alberta comparable to the low-moor, woodland and grassland associations had an annual herbage production of 5323, 520 and 1600 kg/ha D.M., respectively. Hilton (1970) using similar Central Alberta community-types found approximately 3800, 500 and 1100 kg/ha D.M., respectively. The woodland and grassland associations in the present study appeared to be comparable with the results obtained by Wroe (1971) and Hilton (1970) (Tables 10, 16, 21). The low-moor association of the present study however, appeared to be less productive than that found by Wroe (1971) and Hilton (1970). No communities comparable to the shoreline association were studied by Wroe (1971) or Hilton (1970).

The annual herbage weight for each plot was found to be significantly correlated with soil pH ($r=0.47$), tree density ($r=-.38$), and total herbage cover ($r=0.26$) of that plot (Table 4) while the annual herbage weight cluster mean was correlated with soil pH ($r=0.64$) and total herbage cover ($r=0.56$) means (Table 5). Since soil pH was reduced following the invasion of *Populus tremuloides* (Dormaer and Lutwick, 1966), the reduction of the annual herbage weight appeared to be directly attributable to the density of the trees.

The plot grass and grass-like weight was significantly correlated with tree density ($r=-.44$), sodium level ($r=0.42$), soil pH ($r=0.41$) and soil moisture ($r=0.40$) (Table 4). The cluster grass and grass-like weight mean was only significantly correlated with the sodium level ($r=0.65$) and elevation ($r=-.63$). Since the grass and grass-like species weight was a component of the annual herbage weight, it also appeared to be influenced by the tree density.

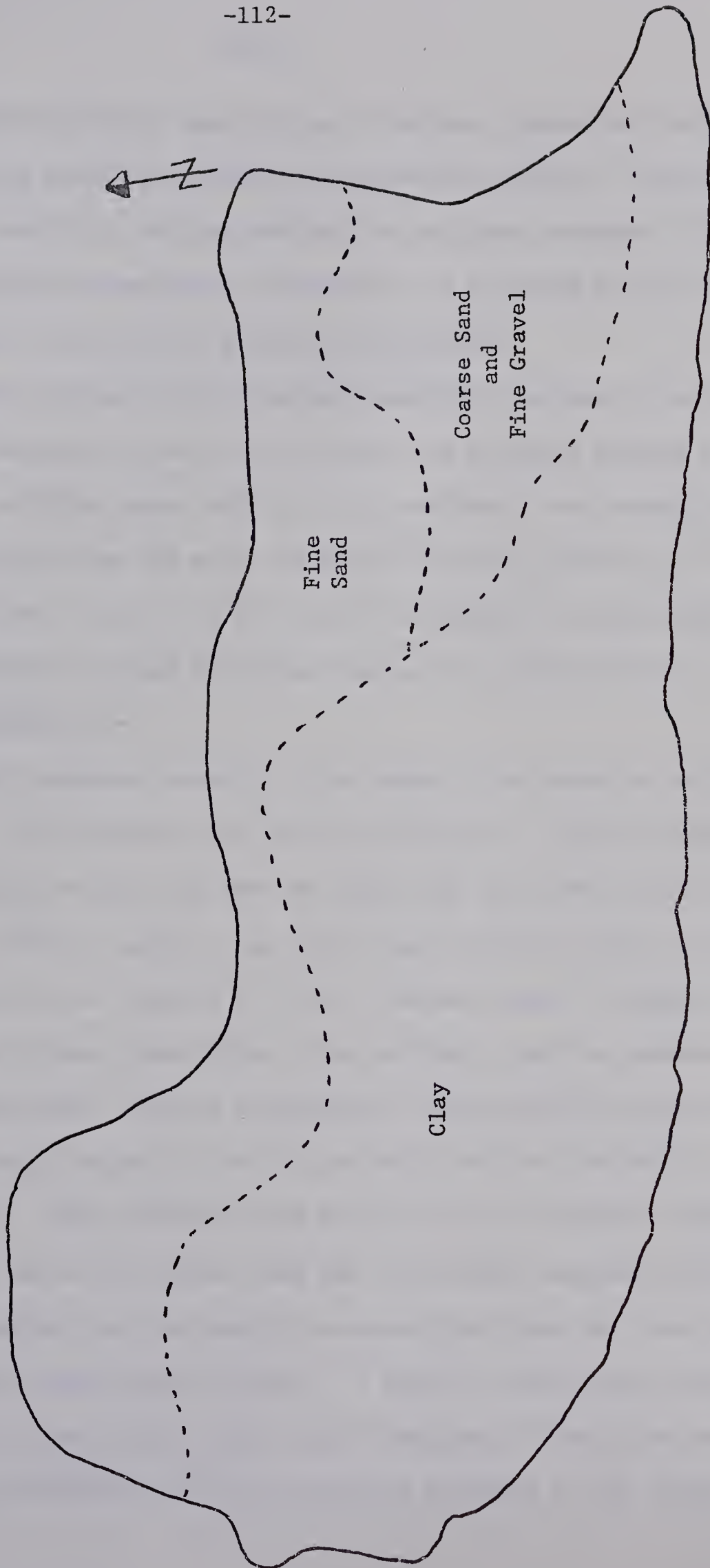
The environmental and edaphic variables which were significantly correlated with the tree density were soil moisture ($r=-.49$), soil pH ($r=-.40$), August soil temperature ($r=-.36$), sodium ($r=-.31$) and July soil temperature ($r=-.27$) (Table 4). The tree density was also significantly correlated with the X-axis ($r=-.72$) (Table 6). Therefore it would appear from this data that the invasion of the woody species as expressed by tree density had a significant influence upon the classification of vegetation and the reduction of potential herbage production in the woodland association.

IV. Soils of the Study Area

Soils on the island were found to be of the Regosolic Order. Horizon development was not detected in the two soil pits dug and probings at each plot in the island study unit failed to show any substantial development. The texture of the parent material consisted of three types; fine sand, coarse sand and fine gravel, and clay (Figure 21). The upland soil was classified as Orthic Regosol having a 0-5 cm LH horizon above a C horizon. The color of the C horizon in the till was dark greyish brown (10YR4/2m). The lowland soil was also classified as Orthic Regosol; however, Cumulic Regosol and Gleyed Regosol profiles were found. It was assumed that the vegetation has not had a profound effect upon soil development and the vegetation and soil have not reached an equilibrium since the recent exposure of the island above the lake level some 40 years ago.

Species which were more common in the eastern section of the island were *Populus tremuloides*, *Poa pratensis*, *Trifolium repens*, *Cirsium arvense* and *Sonchus arvensis*. *Populus balsamifera*, *Salix bebbiana* var. *perrostrata*, *Salix petiolaris*, *Calamagrostis neglecta* and *Carex atherodes* were most common in the western section. *Melilotus alba* was most common in the center of the island. Stands of the woodland association were much more dense in the western section than the east (Figure 1). Herbage production was much reduced in all woodland stands of the western section while *Poa pratensis* could be found forming a prominent stratum under the relatively open woodland canopy in the eastern section. This difference in woodland stands appeared to be related to the texture of the parent material. The coarse sand and fine gravel would likely provide a

Figure 21. The texture of the parent material on the study island.



continuous water table at about 60 cm. Nutrient status would probably be the limiting factor for growth in the eastern section. The western section was underlain by high sodium clay and water movement from the lake was probably non-existent. Therefore the limiting factor for growth in the western section would probably be moisture.

The division in the woodland vegetation between the eastern and western sections did not coincide with the division between the coarse sand and fine gravel and the clay sections. The vegetation division occurred some 200 m to the west of the soil division. This 200 m section was composed of the eastern woodland type surrounding a central grassland in which *Melilotus alba* and *Poa pratensis* were dominants (Figure 1).

Soil moisture analysis of the upper 15 cm revealed the *Populus tremuloides* - *Poa pratensis* and the *Poa pratensis* - *Populus tremuloides* - *Populus balsamifera* clusters were on drier soil than the other clusters (Table 8). Transect number 8 was drier than transect number 10 in the middle of the island (Figures 10, 11). Transect number 8 passed through stands of the *Populus tremuloides* - *Poa pratensis* and *Poa pratensis* - *Populus tremuloides* - *Populus balsamifera* clusters while transect number 10 passed through stands of the *Poa pratensis* and *Poa pratensis* - *Melilotus alba* clusters. Soil moistures from the few plots of transect number 8 which were found in the coarse sand and fine gravel textured parent material revealed that the upper 15 cm were drier than the clay textured parent material immediately adjacent. A stand of the *Populus tremuloides* - *Poa pratensis* covered both types of soil textures. This drier condition was probably accounted for by the excessive drainage of the coarse

textured parent material. Although soil texture appeared to be subtly influencing the distribution of the vegetation, further work would need to be done to determine cause and effect relationships which exist between soil texture and vegetation.

V. Ordinal Classification

A. Advantages

Daubenmire (1952) suggested that the study of the vegetative structure was a practical means of recognizing ecosystems. He also suggested that it was more efficient to study vegetation using conscious stand selection. Greg-Smith (1964) also reported that stand selection was profitable but cautioned that conscious stand selection may present discontinuities in the data which in reality did not exist. Bray and Curtis (1957) suggested that vegetation-environment relationships should be derived from a direct analysis of the quantitative vegetational data rather than from stands which had been previously classified. In their quest to find the relationships between stands, Bray and Curtis (1957) ignored the basic structure of the vegetation, i.e., the community. This information had to be extrapolated from the ordination.

In ordinal classification, an attempt has been made to present the botanical information of community structure in the relative continuity or discontinuity of the vegetation inherent in the study unit. Ordinal classification appeared to combine the community structure of Daubenmire (1952) and the stand relationships of Bray and Curtis (1957). This approach delimited the clusters (communities) and displayed the relationships among the clusters.

In the present study, the conscious stand selection was attempted

in the reconnaissance study unit; however, the successional stage of the vegetation on the island rendered stand selection impractical. A restricted random method of plot location resulted in all vegetation having an equal opportunity of being sampled. This has been clearly illustrated in the clusters of the island study unit. The major clusters were representative of the predominant vegetational groupings and appeared to be analogous to those communities which would have been formed through conscious stand selection, i.e., following the method of Daubenmire (1952). On the other hand, the minor clusters would probably have been ignored during conscious stand selection as they appear to be representative of the ecotones between the major clusters. The *Sonchus arvensis*, *Mentha arvensis* var. *villosa* and *Populus balsamifera* clusters seemed to represent the adaptation of a species to a localized habitat (Table 13). The stands of these three clusters were found widely dispersed on the island and represented a small percentage of the vegetation (Table 20). The other minor clusters presented an example of the ecotones which existed between the major clusters (Table 18). By including the minor clusters in the orthogonal cluster ordination, the vegetational continuum inherent in the data was expressed (Figure 15). Rejection of these minor clusters produced large discontinuities between the major clusters (Figure 16). Ordinal classification presented a more complete expression of the vegetational structure of the island study unit than either plot ordination or conscious stand selection because ordinal classification:

- (a) defined subsets of similar plots (clusters) (Appendices 1, 3),
- (b) presented the community structure inherent in the data

(Table 18), and

(c) maintained the relative positions of the cluster during cluster ordination (Figures 6, 7, 12, 13).

B. Problems

A problem similar to that encountered by Swan et al. (1969) was experienced in the present study. If no species clearly dominated the plot, this plot could not be properly classified. Plots which had no dominant species tended to form heterogeneous clusters, i.e., the "Ecotonal" cluster in Appendix 1. This heterogeneous, low-cover cluster resulted from relatively short intersite distances between plots in the cluster. The short distances were not a result of plot similarities but were a result of relatively low-cover values of species which dominated the plots. The majority of these "low-cover" plots were found along the ecotone between the upland and lowland zones. An example of this ecotone has been given in Figure 14. The canopy coverage of the dominant herbaceous species usually occupied less than 50% of the plot area while the remainder was litter or bare ground. The reduction in the canopy coverage was probably caused by the competition for soil nutrients and moisture by the roots of the adjacent *Salix* plants. It was observed that the root zone, as measured by the reduction in canopy coverage of herbaceous species, was much larger than the coverage of the *Salix* canopy (Figure 19). Plots falling within the *Salix* root zone but outside the canopy were highly variable; species composition changed erratically and annual herbage weight ranged from 250 kg/ha D.M. to 3200 kg/ha D.M.

In the present study, these "low-cover" plots distorted

classification. Since there were only two transects in the gradient study unit, few "low-cover" plots were encountered and these have been left as a heterogeneous cluster ("Ecotonal" cluster, Appendix 1). In the island study unit, plot normalization eliminated the problem of "low-cover" plots because it scaled the cover values of the dominant species in each plot to 100 and proportionally adjusted the remaining cover values. This method equalized the cover values of the dominant species in each plot so that each plot entered ordination with a common base. Plot normalization did not appear to change the basic structure of the vegetation (Table 18); however, the basic canopy coverage data was lost.

VI. Relevance to Range Management

Ordination classification has provided a method for delineating groupings of vegetation which can be subjected to statistical analysis. Since herbage production was the primary interest in this study, significant differences have been shown between clusters for the herbage production variables as well as between associations. Range management decisions can be based upon these differences.

SUMMARY AND CONCLUSIONS

The synthesis of ordination and cluster analysis in the present study has been termed ordination classification. Ordination classification presented the community structure of the vegetation and the relationships among groupings of vegetation. Two methods for determining the intersite distance have been presented. These were the Euclidean and Arithmetic distances. Problems encountered from low-cover dominant species have been overcome in the present study by using plot normalization. It was more advantageous to sample the successional vegetation using a method of restricted random plot selection rather than conscious stand selection.

It was found that presence cover, mean cover or prominence index were reliable indicators of the influence of an independent species in ordination classification. Mean cover was most closely correlated with the dissimilarity index of the independent species. *Poa pratensis* and *Calamagrostis neglecta* were the two most dissimilar species. *Poa pratensis* defined the upland zone and *Calamagrostis neglecta* defined the lowland zone. The other independent species were found to fall into either of the two zones.

The orthogonal axes defined during ordination were found to be closely associated with environmental and edaphic factors. The first (X) orthogonal axis was significantly correlated with elevation, soil moisture, sodium, tree density, depth of organic soil, shrub density and grass and grass-like weight. During regression analysis, 95% of the variation in the X-axis was accounted for by elevation, shrub density and tree density. The X-axis defined the upland and lowland zones.

The second (Y) orthogonal axis was significantly correlated with June soil temperature, forb weight and annual herbage weight. Regression analysis of the Y-axis included June soil temperature, August soil temperature and phosphorous as the significant factors. These factors accounted for 80% of the variation in the Y-axis.

The third (Z) orthogonal axis was significantly correlated with phosphorous, elevation, soil pH and soil moisture. The regression analysis which accounted for 71% of the variation of the Z-axis included phosphorous and soil pH as defining factors. Phosphorous was the only significant factor.

Three vegetation associations were defined. These were the shoreline, low-moor and woodland associations. A fourth association, the grassland association, was also defined when the study unit was intensively sampled. The shoreline and low-moor associations were found within the lowland zone. These associations were defined by the Z-axis. The woodland and grassland associations were found in the upland zone. This division was suggested by the Y-axis; however, an arbitrary separation was made in the present study to test the reduction of the potential herbage production following the invasion of woody species.

The annual herbage productions of the shoreline, low-moor and grassland associations were not significantly different. The woodland association was significantly less productive. The invasion of woody species reduced the annual herbage production by approximately 68%.

The soils in the study area were of the Regosolic Order. The vegetation has not had a profound effect upon soil development and an equilibrium between vegetation and soil has not been reached.

BIBLIOGRAPHY

- Anonymous. 1915. Edmonton Sheet Sectional Map. Office of the Surveyor General, Government of Canada, Ottawa.
- Austin, M.P. and L. Orloci. 1966. Geometric models in ecology: II. An evaluation of some ordination techniques. J. Ecol. 54: 217-227.
- Ayyad, M.A.G. and R.L. Dix. 1964. An analysis of a vegetation-micro-environmental complex on prairie slopes in Saskatchewan. Ecol. Mono. 34: 421-442.
- Beals, A.W. 1960. Forest bird communities in the Apostle Islands of Wisconsin. Wilson Bulletin 72: 156-181.
- Bird, R.D. 1961. Ecology of the aspen parkland of western Canada. Can. Dep. Agr. Pub. 1066, Ottawa. 153pp.
- Bowser, W.E., A.A. Kjearsgaard, T.W. Peters and R.E. Wells. 1962. Soil survey of Edmonton sheet (83-H). Univ. of Alberta Bull. No. SS-4, Alberta Soil Survey Report No. 21.
- Bray, J.R. and J.T. Curtis. 1957. An ordination of the upland forest communities of southern Wisconsin. Ecol. Mono. 27: 325-349.
- Carmichael, J.W., J.A. George and R.S. Julius. 1968. Finding natural clusters. Syst. Zool. 17: 144-150.
- Carmichael, J.W. and P.H.A. Sneath. 1969. Taxometric maps. Syst. Zool. 18: 402-415.
- Carmichael, J.W. 1970. The taxmap classification program. Dep. of Bacteriology. Univ. of Alberta. (Published by Carmichael and Sneath (1969)).
- Cole, L.C. 1949. The measurement of interspecific association. Ecol. 30: 411-424.
- Cole, L.C. 1957. The measurement of partial interspecific association. Ecol. 38: 226-233.
- Daubenmire, R. 1952. Forest vegetation of northern Idaho and adjacent Washington, and its bearing on concept of vegetational classification. Ecol. Mono. 22: 301-330.
- Daubenmire, R. 1959. A canopy coverage method of vegetational analysis. Northwest Sci. 33: 43-64.
- Daubenmire, R. 1968. Plant Communities: A Textbook of Plant Synecology. New York: Harper and Row. 300pp.

- Dix, R.L. and F.E. Smeins. 1967. The prairie, meadow and marsh vegetation of Nelson County, North Dakota. *Can. J. Bot.* 45: 21-58.
- Dormaar, J.F. and L.E. Lutwick. 1966. A biosequence of soils of the rough fescue prairie-poplar transition in southwestern Alberta. *Can. J. Earth Sciences* 3: 467-471.
- George, J.A. and J.W. Carmichael. 1966. An algorithm for finding natural clusters. Dep. of Computing Sci. Univ. of Alberta. 100pp. (Published by Carmichael et al. (1968)).
- Gittens, R. 1965a. Multivariate approaches to a limestone grassland community. I. A stand ordination. *J. Ecol.* 53: 385-401.
- Gittens, R. 1965b. Multivariate approaches to a limestone grassland community. II. A direct species ordination. *J. Ecol.* 53: 403-409.
- Gleason, H.A. 1926. The individualistic concept of the plant association. *Bull. Torrey Bot. Club* 53: 7-26.
- Goodall, D.W. 1954. Objective methods for the classification of vegetation. III. An essay in the use of factor analysis. *Aust. J. Bot.* 2: 304-324.
- Greg-Smith, P. 1964. Quantative Plant Ecology. 2nd ed. Butterworths, London. 256pp.
- Grobhen, G. 1970. Stepwise multiple regression. Dep. of Computing Sci. Univ. of Alberta.
- Hilton, J.E. 1970. Forage production and utilization in the aspen parkland of Alberta following aerial application of 2,4-D and 2,4,5-T. M.Sc. thesis. Univ. of Alberta. Unpublished.
- Lambert, J.M. and M.B. Dale. 1964. The use of statistics in phytosociology. *Adv. in Ecol. Res.* 2: 59-100.
- La Roi, G.H. 1964. An ecological study of the boreal spruce-fir forests of the North American taiga. Ph.D. thesis. Duke University, North Carolina. Unpublished.
- Lewis, F.J., E.S. Dowding and E.H. Moss. 1928. Vegetation of Alberta. II. The swamp, moor and bog forest vegetation of central Alberta. *J. Ecol.* 16: 19-70.
- Li, J.C.R. 1964. Statistical Inference I. Edwards Brothers Inc. Ann Arbor, Michigan. 658pp.
- Lindquist, E.F. 1971. The Norton study of the effects of non-normality and heterogeneity of variance. Contemporary Problems of Statistics. B. Lieberman ed. Oxford University Press, London.

- Moss, E.H. 1953. Marsh and bog vegetation in northwestern Alberta. Can. J. Bot. 31: 448-470.
- Moss, E.H. 1955. The vegetation of Alberta. Bot. Rev. 21: 493-567.
- Moss, E.H. 1959. Flora of Alberta. University of Toronto Press, Toronto. 546pp.
- Orloci, L. 1966. Geometric models in ecology. I. The theory and application of some ordination methods. J. Ecol. 54: 193-215.
- Pettapiece, W.W. 1969. The forest-grassland transition. Pedology and Quaternary Research. S. Pawluk ed. Symposium sponsored by the National Research Council of Canada and the Univ. of Alberta. 218pp.
- Purchase, J.E. 1970a. Computer program EUCLID. Plant Ecol. Laboratory, Dep. of Bot. Univ. of Alberta. Unpublished.
- Purchase, J.E. 1970b. Computer program SDWORD. Plant Ecol. Laboratory, Dep. of Bot. Univ. of Alberta. Unpublished.
- Sheffé, H. 1959. Analysis of Variance. Wiley and Sons Inc. New York.
- Sokal, R.R. and P.H.A. Sneath. 1963. Numerical Taxonomy. W.H. Freeman and Co., London. 359pp.
- Steel, R.G.D. and J.H. Torrie. 1960. Principles and Procedures of Statistics. McGraw-Hill. Toronto. 481pp.
- Stringer, P. 1969. Ecological study of grasslands at low elevation in Banff, Jasper and Waterton Lake National Parks. Ph.D. thesis. Dep. of Botany. Univ. of Alberta.
- Swan, J.M.A., R.C. Dix and C.F. Wehrhahn. 1969. An ordination technique based on the best possible stand-defined axes and its application to vegetation analysis. Ecol. 50: 206-212.
- Walker, B.H. and R.T. Coupland. 1968. An analysis of vegetation-environment relationships in Saskatchewan sloughs. Can. J. Bot. 46: 509-522.
- Williams, W.T. and J.M. Lambert. 1959. Multivariate methods in plant ecology. I. Association-analysis in plant communities. J. Ecol. 47: 83-101.
- Williams, W.T. and J.M. Lambert. 1961. Multivariate methods in plant ecology. III. Inverse association-analysis. J. Ecol. 49: 717-729.
- Wroe, R.A. 1971. Synecology of a *Festuca scabrella* Torr. grassland. M.Sc. thesis. Dep. of Plant Sci. Univ. of Alberta. Unpublished.

APPENDICES

Appendix 1. Canopy coverage (%) of important species defining the replicated clusters in the gradient study unit.

[illegible]¹ Predominantly *Poa pratensis* with some *Poa compressa* and *Poa glaucifolia*.² Predominantly *Carex atherodes* with some *Carex rostrata*.

Appendix 2. Dominant and subdominant species defining the single plot clusters in the gradient study unit.

SPECIES	PLOT NO.	801	809	812	813	814	816	834	835	1002	1003	1010	1012	1013	1016	1018	1024	1025	1038
<i>Poa pratensis</i> ¹					37.0										63.0		85.0	63.0	
<i>Calamagrostis neglecta</i>								85.0											
<i>Populus tremuloides</i>							97.0							37.0			97.0	97.0	
<i>Salix bebbiana</i> var. <i>permostrata</i>			97.0										97.0				63.0	85.0	
<i>Melilotus alba</i>														63.0					
<i>Populus balsamifera</i>														37.0	63.0	85.0	63.0		
<i>Cirsium arvense</i>		37.0								37.0									
<i>Carex atherodes</i> ²										37.0									
<i>Sonchus arvensis</i>										37.0									
<i>Salix petiolaris</i>			63.0					37.0											
<i>Scirpus validus</i>												37.0							
<i>Solidago</i> spp.						85.0													37.0
<i>Urtica gracilis</i>		37.0																	
<i>Calamagrostis inexpansa</i>									37.0										
<i>Rosa</i> spp.							63.0												
<i>Carex praegracilis</i>				37.0															

¹Predominantly *Poa pratensis* with some *Poa compressa* and *Poa glaucifolia*.²Predominantly *Carex atherodes* with some *Carex rostrata*.

Appendix 3. Canopy coverage (%) of important species defining the replicated clusters

CLUSTER		<i>Scirpus validus</i> - <i>Cirsium arvense</i> - <i>Sonchus arvensis</i>			<i>Scolochloa</i> <i>festuacea</i>			<i>Carex atherodes</i> - <i>Calamagrostis neglecta</i>																<i>Poa pratensis</i> - <i>Salix</i> <i>bebbiana</i> var. <i>perrostrata</i>					<i>Populus</i> <i>tremuloides</i> - <i>P. pratensis</i> / <i>bebbiana</i> var. <i>perrostrata</i>		<i>Populus</i> <i>tremuloides</i> - <i>Poa</i> <i>pratensis</i>			As												
PLOT NO.		69	70	68	57	66	61	62	64	52	50	60	67	54	63	59	56	58	65	47	48	44	46	43	42	34	35	41	40	32	29	38	30	39		6										
SPECIES	CODE																																		CODE											
<i>Poa pratensis</i> ¹	Popr																									3.0	3.0	15.0	3.0	3.0						63.0	63.0	63.0	38.0	85.0	63.0	63.0	63.0	85.0	Popr	85.0
<i>Calamagrostis neglecta</i> ²	Cane	3.0 38.0			15.0	15.0	63.0	3.0	15.0	38.0	38.0	63.0	63.0	98.0	98.0	98.0	85.0	98.0	85.0	63.0	63.0	63.0	38.0	15.0	3.0												Cane									
<i>Carex atherodes</i> ³	Caat	38.0	15.0		15.0	15.0	38.0	98.0	98.0	85.0	63.0	85.0	85.0	63.0	63.0	38.0	38.0	38.0	15.0	63.0	85.0	63.0	38.0	38.0	38.0													Caat								
<i>Populus tremuloides</i>	Potr																									63.0	38.0	38.0 63.0		98.0	98.0	98.0	98.0			Potr										
<i>Cirsium arvense</i>	Ciar	85.0	63.0	38.0				3.0																			15.0	38.0	15.0								3.0			Ciar	15.0					
<i>Melilotus alba</i>	Meal																									15.0	3.0	38.0	63.0	3.0	3.0			Meal												
<i>Taraxacum</i> spp.	Tas.																									3.0	3.0			3.0	15.0	15.0	38.0	Tas.	15.0											
<i>Salix bebbiana</i> var. <i>perrostrata</i>	Sabe							3.0																		15.0	38.0			63.0	63.0	85.0	63.0	15.0	63.0	63.0	3.0			Sabe						
<i>Astragalus agrestis</i>	Asag																									3.0 15.0					3.0			3.0 3.0	Asag											
<i>Juncas balticus</i>	Juba	3.0						15.0 15.0																			15.0	15.0 38.0 63.0		15.0			Juba													
<i>Sonchus arvensis</i>	Soar	63.0	63.0	38.0				15.0																		3.0	3.0				Soar															
<i>Astragalus canadensis</i>	Asca																									3.0	15.0	3.0				Asca	63.0													
<i>Fragaria virginiana</i> var. <i>glauca</i>	Frvi																									3.0	3.0 3.0 3.0 3.0		15.0	38.0	15.0	38.0	Frvi													
<i>Ephilobium angustifolium</i>	Epan																									3.0			15.0			Epan	3.0													
<i>Achillea millefolium</i>	Acmi																									3.0	3.0	3.0	15.0	15.0	3.0 3.0		Acmi	15.0												
<i>Scirpus validus</i>	Scva	63.0	98.0	38.0				38.0																									Scva													
<i>Scolochloa festuacea</i>	Scfe				98.0	98.0	63.0	15.0 3.0																		15.0			Scfe																	
<i>Solidago</i> spp.	Sos.																									15.0							Sos.													
<i>Aster pansis</i>	Aspa																									15.0	15.0	3.0				Aspa	3.0													
<i>Lactuca pulchella</i>	Lapu																									15.0					3.0	3.0	3.0	3.0	Lapu	15.0										
<i>Salix petiolaris</i>	Sape																									15.0	15.0	15.0							Sape											
<i>Populus balsamifera</i>	Poba																									38.0	15.0	15.0	3.0	3.0		3.0	Poba													
<i>Mentha arvensis</i> var. <i>villosa</i>	Mear	3.0			3.0			3.0 15.0 3.0												15.0	15.0	15.0 15.0 15.0							Mear																	

¹Predominantly *Poa pratensis* with some *Poa compressa* and *Poa glaucifolia*.
²Predominantly *Calamagrostis neglecta* with some *Calamagrostis inexpansa*.
³Predominantly *Carex atherodes* with some *Carex rostrata*.

Appendix 3. Canopy coverage (%) of important species defining the replicated clusters in the reconnaissance study unit.

					<i>Poa pratensis</i> - <i>Salix bebbiana</i> var. <i>perrostrata</i>					<i>Populus tremuloides</i> - <i>P. pratensis</i> / <i>S. bebbiana</i> var. <i>perrostrata</i>		<i>Populus tremuloides</i> - <i>Poa pratensis</i>		<i>Poa pratensis Astragalus canadensis</i>					<i>Poa pratensis</i> - <i>Melilotus alba</i>		<i>Poa pratensis</i>																<i>Poa pratensis</i> - <i>Taraxacum</i> spp.							
44	46	43	42		34	35	41	40	32	29	38	30	39		6	16	18	10	17	1	2	8	23	9	4	25	19	14	11	20	21	36	33	37	28	26	5	24	12	13				
0	15.0	3.0	3.0		63.0	63.0	63.0	38.0	85.0	63.0	63.0	63.0	85.0	Popr	85.0	85.0	85.0	85.0	98.0	85.0	98.0	98.0	98.0	85.0	98.0	85.0	63.0	98.0	98.0	98.0	63.0	63.0	63.0	98.0	85.0	85.0	98.0	85.0	85.0	98.0	85.0	85.0	98.0	
0	63.0	38.0	15.0		3.0									Cane																												85.0	98.0	
0	63.0	38.0	38.0	38.0										Caat																														
					63.0	38.0		38.0	63.0	98.0	98.0	98.0	98.0	Potr							3.0					15.0	15.0					15.0	3.0	15.0										
0	38.0	15.0						3.0				3.0	3.0	Ciar	15.0		3.0			3.0	3.0			15.0	38.0	38.0		15.0	3.0	3.0	15.0	15.0	63.0					3.0						
			3.0	3.0	15.0	3.0	38.0	63.0	3.0	3.0		15.0	38.0	Meal		15.0	15.0	3.0	63.0	98.0	63.0			3.0	3.0	3.0	3.0	15.0	15.0	3.0	3.0	3.0		15.0	3.0	3.0	3.0	15.0	3.0	38.0	3.0			
	15.0	38.0			63.0	63.0	85.0	63.0	15.0	63.0	63.0	3.0		Tas.	15.0	3.0	38.0	38.0	15.0	38.0	38.0			3.0	3.0	3.0	15.0	15.0	15.0	3.0	3.0	3.0		3.0	3.0	3.0	15.0	15.0	15.0	63.0	38.0			
												3.0		Sabe																			3.0	3.0	15.0									
							3.0	15.0		3.0		3.0	3.0	Asag		15.0			15.0	15.0	38.0			3.0	3.0	15.0	38.0	38.0	63.0	63.0	15.0		3.0	3.0	15.0	3.0	15.0		63.0	15.0				
	15.0	38.0	63.0			15.0		15.0						Juba		15.0		15.0															3.0	15.0	3.0									
3.0			3.0				15.0							Soar			15.0	3.0				3.0		15.0	3.0			15.0		38.0		3.0	3.0		15.0									
				3.0	3.0	15.0			3.0	15.0	38.0	15.0	38.0	Asca	63.0	63.0	98.0	85.0	38.0	15.0				3.0	3.0							3.0			15.0	3.0								
						3.0	3.0	3.0	3.0	15.0	38.0	15.0	38.0	Frvi		3.0	15.0	15.0	15.0	38.0	15.0		15.0			3.0		3.0	15.0	38.0	3.0		15.0	3.0	3.0	3.0		15.0	3.0					
							3.0				15.0		15.0	Epan	3.0	15.0	3.0	38.0	15.0						38.0										63.0	3.0	63.0							
						3.0	3.0	3.0	15.0	15.0		3.0	3.0	Acmi	15.0	15.0	15.0	15.0	15.0	3.0	3.0			3.0	3.0	3.0	15.0	15.0	15.0	15.0	3.0	15.0	3.0		3.0		15.0	15.0						
														Scva																														
														Scfe																														
							15.0				15.0		15.0	Sos.						15.0	38.0											15.0	38.0	3.0										
					15.0	15.0		3.0				3.0		Aspa	3.0			3.0	15.0	3.0	3.0		15.0		3.0	3.0		15.0	15.0	3.0	38.0		15.0	3.0	15.0		3.0	15.0						
0			15.0				15.0			3.0	3.0	3.0	3.0	Lapu	15.0	15.0	3.0		3.0	3.0	15.0		3.0	3.0	3.0	15.0	3.0		3.0	15.0					15.0	3.0	3.0	3.0						
					15.0	3.0								Sape																		3.0		38.0										
0		15.0	15.0	15.0							3.0	3.0		Poba			3.0			3.0						3.0	15.0					3.0		3.0		3.0	38.0							
														Mear																														

Appendix 4. Dominant and subdominant species defining the single
plot clusters in the reconnaissance study unit.

SPECIES	PLOT NO.	3	7	15	22	27	31	45	49	51	53	55
<i>Poa pratensis</i> ¹		98.0	98.0		63.0	63.0	98.0					
<i>Calamagrostis neglecta</i> ²									85.0	38.0	38.0	63.0
<i>Carex atherodes</i> ³										63.0	38.0	
<i>Cirsium arvense</i>					85.0							
<i>Melilotus alba</i>				63.0								
<i>Salix bebbiana</i> var. <i>perrostrata</i>								85.0				
<i>Juncus balticus</i>									63.0			
<i>Carex praegracilis</i>									63.0			
<i>Sonchus arvensis</i>				63.0								
<i>Astragalus</i> spp.		63.0										
<i>Fragaria virginiana</i> var. <i>glauca</i>						38.0						
<i>Ephilobium angustifolium</i>						63.0						
<i>Achillea millefolium</i>						38.0						
<i>Scirpus validus</i>												85.0
<i>Solidago</i> spp.							98.0					
<i>Salix petiolaris</i>										63.0		
<i>Artemisia ludoviciana</i> var. <i>graphalodes</i>		98.0										
<i>Thermopsis rhombifolia</i>			85.0									

¹Predominantly *Poa pratensis* with some *Poa compressa* and *Poa glaucifolia*.

²Predominantly *Calamagrostis neglecta* with some *Calamagrostis inexpansa*.

³Predominantly *Carex atherodes* with some *Carex rostrata*.

Appendix 5. Botanical and common names of plant species.

<i>Achillea millefolium</i>	Common yarrow
<i>Artemisia biennis</i>	Biennial wormwood
<i>Artemisia ludoviciana</i> var. <i>gnaphalodes</i>	Prairie sage
<i>Aster hesperius</i>	Western willow aster
<i>Aster pansus</i>	Many-flowered aster
<i>Astragalus agrestis</i>	Purple milk-vetch
<i>Astragalus canadensis</i>	Canadian milk-vetch
<i>Astragalus flexuosus</i>	Slender milk-vetch
<i>Beckmannia syzigachne</i>	Slough grass
<i>Calamagrostis americana</i>	Reed grass
<i>Calamagrostis canadensis</i>	Marsh reed grass
<i>Calamagrostis inexpansa</i>	Northern reed grass
<i>Calamagrostis neglecta</i>	Narrow reed grass
<i>Carex atherodes</i>	Awned sedge
<i>Carex lasiocarpa</i>	Woolly sedge
<i>Carex praegracilis</i>	Graceful sedge
<i>Carex rostrata</i>	Beaked sedge
<i>Cirsium arvense</i>	Canada thistle
<i>Epilobium angustifolium</i>	Fireweed
<i>Festuca scabrella</i>	Rough fescue
<i>Fragaria virginiana</i> var. <i>glauc</i>	Wild strawberry
<i>Glyceria grandis</i>	Manna grass
<i>Hordeum jubatum</i>	Wild barley
<i>Juncus balticus</i>	Baltic rush
<i>Lactuca pulchella</i>	Blue lettuce

Appendix 5. Continued.

<i>Melilotus alba</i>	White sweet clover
<i>Mentha arvensis</i> var. <i>villosa</i>	Wild mint
<i>Phalaris arundinacea</i>	Reed canary grass
<i>Phragmites communis</i>	Giant reed grass
<i>Poa compressa</i>	Canada bluegrass
<i>Poa glaucifolia</i>	Glaucous bluegrass
<i>Poa palustris</i>	Fowl bluegrass
<i>Poa pratensis</i>	Kentucky bluegrass
<i>Polygonum aviculare</i>	Common knotweed
<i>Populus balsamifera</i>	Balsam poplar
<i>Populus tremuloides</i>	Aspen poplar
<i>Rumex</i> spp.	Sorrel
<i>Salix bebbiana</i> var. <i>perrostrata</i>	Beaked willow
<i>Salix interior</i>	Sandbar willow
<i>Salix petiolaris</i>	Pussy willow
<i>Scirpus validus</i>	Great common bullrush
<i>Secolochloa festuacea</i>	Whitetop
<i>Sonchus arvensis</i>	Sow thistle
<i>Taraxacum officinale</i>	Common dandelion
<i>Thermopsis rhombifolia</i>	Golden bean
<i>Trifolium repens</i>	Alsike clover
<i>Typha latifolia</i>	Common cattail
<i>Urtica gracilis</i>	Common nettle

B30015